DEPARTMENT.

DEPARTMENTAL COMMITTEE ON SPONTANEOUS COMBUSTION OF COAL IN MINES.

FINAL REPORT

OF THE

DEPARTMENTAL COMMITTEE

ON

SPONTANEOUS COMBUSTION OF COAL IN MINES.

(*The First Report of the Committee was presented as Cd.* 7218 *of Session* 1914.)

Presented to Parliament by Command of His Majesty.

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MINES DEPARTMENT.

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1921.

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The total cost of the Committee's investigation has been 1,070*l*.

The cost of printing and publishing the Committee's First and Final Reports and the Minutes of Evidence (three volumes) is estimated at 980*l*.

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WARRANTS OF APPOINTMENT.

I hereby appoint:

*Mr. R. A. S. REDMAYNE, C.B., H.M. Chief Inspector of Mines,
Sir ARTHUR B. MARKHAM, Bt., M.P.,
Mr. C. E. RHODES,
Mr. FRANK RIGBY, and
Mr. HERBERT SMITH;

to be a Committee to inquire into the circumstances in which spontaneous combustion of coal occurs in mines, its causes and the means of preventing it or of dealing with it when it has arisen.

(Signed) R. McKENNA.

Whitehall,
5th August, 1912.

I hereby appoint:

Mr. J. H. W. LAVERICK;

to be a Member of the Committee appointed in 1912 to inquire into the circumstances in which spontaneous combustion of coal occurs in mines, in the place of the late Sir Arthur Markham.

(Signed) E. SHORTT.

Whitehall,
2nd February, 1920.

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* Since 1913, Sir R. A. S. Redmayne, K.C.B.

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ALPHABETICAL LIST OF WITNESSES.

The Minutes of Evidence have been printed as Stationery Office Publications and are contained in three volumes: Vol. I., 1st to 10th Days with Index; Vol. II., 11th to 22nd Days; Vol. III., 23rd to 26th Days with Index 11th to 26th Days

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FINAL REPORT

OF THE

DEPARTMENTAL COMMITTEE

ON

SPONTANEOUS COMBUSTION OF COAL IN MINES.

Mines Department,
Victoria Street, S.W.1.,
30th June 1921.

To the Right Honourable William Clive Bridgeman, M.P., His Majesty's Secretary for Mines.

Sir,

Eight years have passed since this Committee was appointed by the then Home Secretary, Mr. McKenna, to inquire into the circumstances in which spontaneous combustion occurs in mines, its causes, and the means of preventing it, or of dealing with it when it occurs.

In December of 1913, the Committee presented an interim report on that part of the inquiry relative to the danger to persons employed in a mine during the occurrence of an underground fire occasioned by the spontaneous combustion of coal or other carbonaceous material. We stated in that report that we proposed continuing our investigations in other directions to discover the means which should be adopted towards preventing the initiation of spontaneous fires and the means which should be taken to combat them when they occur. We have so pursued our investigations and now beg to report thereon.

The present Report would have been made some years earlier but for the fact of the recent Great War. Shortly after its outbreak the energies of the Members of the Committee were directed into other channels and continued to be so engaged during the continuance of the war and for some time after the termination of hostilities.

We have to regret the loss through death of two of our colleagues, viz.: Sir Arthur Markham, Bart., M.P., in August 1916, and Mr. C. E. Rhodes in June 1920. The loss of these two gentlemen has been a very real one to the Committee. Sir Arthur Markham not only devoted a great deal of time, energy and thought to the work of the Committee—he was never once absent from its meetings—but, on his own initiative and at his own expense, he undertook a visit, the results of which he reported to the Committee, to the Pas-de-Calais coalfield of France, and to the coalfields of Westphalia and Silesia, with the object of studying the system of hydraulic stowage of mine wastes in operation at some of the collieries in those fields. Mr. Rhodes, a mining engineer of great experience and almost unrivalled knowledge in the methods of laying out and working coal mines in the United Kingdom, was unstinting in his contribution to our deliberations.

On the resumption of the sittings of the Committee, early in 1920, you were pleased to appoint Mr. J. H. W. Laverick as successor to the late Sir Arthur Markham; the place rendered vacant by the death of Mr. C. E. Rhodes was not filled, as it was necessary to hold but few meetings subsequent to his death.

In June 1920 Mr. Herbert Smith wrote that he did not wish to continue to act on the Committee.

The Committee has held in all 28 meetings, 26 of which were devoted to the taking of evidence.

For the sake of convenience we treat the subject of this Report under five main headings, viz.: Section I. contains a short historical review of the subject; Section II. is devoted to the consideration of the cause or causes, from the

scientific point of view, of the initiation of spontaneous combustion in coal mines; Section III. deals with the subject from the practical point of view, *i.e.*, the conditions in the mine which are conducive to the occurrence of self-heating of the coal and the means which should be taken to prevent the occurrence of fires so occasioned, or of dealing with them when they occur; Section IV. deals with the method of filling the waste by hydraulic stowage; and Section V. is devoted to general conclusions and recommendations.

SECTION I.

HISTORICAL REVIEW OF THE SUBJECT.

The originating cause of the self-heating of coal, or "spontaneous combustion" as it has come to be designated, has for many years occupied the attention of mining men, shippers, coal merchants, chemists and physicists. Various reasons and theories have from time to time been advanced to account for and explain the phenomena associated with spontaneous combustion, such as the oxidation of the iron pyrites in the coal, the absorption of oxygen by the coal substance or certain parts thereof, bacterial action, and so forth, but none of these has met with universal acceptation as a solution of the mystery. The first named, viz., the oxidation of iron pyrites in the coal, was for long commonly accepted as the primary and principal cause of spontaneous combustion of coal.

As long ago as 1686, *Dr. Plott*, Keeper of the Ashmolean Museum and Professor of Chemistry in the University of Oxford, in his "Natural History of Staffordshire," wrote: " . . . 'tis agreed they" (various coal mines) "all fired natural of them- " selves, as they expect the shale and small coal in the hollows and deads of all, the old " works, will doe and have done, beyond all memory. Which they say is occasion'd by a " mixture of the Laming (that lyes between the measures of the coal) and the sleck (more " especially when very much mixt with brass lumps) which lying together in the old " caucker'd waters of the pits, heat to that degree, that they fire the small coal left " there, which continues burning till it's all spent, and then goes out of itself as soon " as it comes to the rock of coal, which, if it have no rifts or clefts in it, admits it " not: in-so-much that the inhabitants of these places are not concern'd at it, nor have " half the dread upon them for it, that those have that live remote, far enough out of " its reach. The Worshipful Dud. Dudley in his *Metallum Martis* says that small coal " with sleck thrown moist together (not mentioning anything of Laming) by reason " of its sulphurousness, will doe the same thing; which I am inclined to believe since " I find amongst Dr. Powers' observations that the *Pyrites aureus* being exposed to " the moist Air, or sprinkled with water, will smoak and grow exceeding hot, and " if many be laid in a heap and water'd, will turn red hot of themselves, as he says " he had seen them Himself, whereof he acquaints us with a very unhappy example, " that fell out at Ealand a neighbouring Town to him in Yorksh., where one " Wilson having piled up many cartloads of them in a barn of his (for some secret " purpose of his owne) the roof being faulty, and admitting rain water to fall " copiously in amongst them, they first began to smoak, and at last to take fire and " burn like red hot coales, so that the Town was in an uproar about the quenching of " them. Now if the *golden Marchasit* or brass lumps alone will thus take fire, " much more will they fire when mixt with small coal: whereby as Dr. Jorden assures " us whole heaps of coals mixt with this sort of *Pyrites* (call'd *metall coals*) have taken " fire at Puddle wharfe in London, and at New-Castle, and been burnt before their " time.

" When 'tis plain how likely it is that the coal pits at Wednesbury &c., take fire " of themselves, in which there is so much Sulphur which sublimes by the heat of the " fire from the Pyrites in the coal. . . ."

Berzelius (1779–1848), the Great Swedish chemist, was the first scientist of repute, after Plott, to suggest that the heat evolved by the oxidation of the pyrites in coal might have an important bearing on the cause of spontaneous ignition,* and at the beginning of the 19th century this theory was that generally accepted.

John Finch wrote "an account of a *Pseudo-Volcano* in the neighbourhood of " Bradley Ironworks, Staffordshire, and of some mineral Substance found there,"

* Report of the Sixty-first meeting of the British Association for the Advancement of Science, August, 1891. "The Spontaneous Ignition of Coal" by Prof. Vivian B. Lewes, page 602.

which was published in 1818.* He described the fire at length, asserting that it had been mentioned by Plott in 1686, and attributed its origin to the sulphur contained in the coal and pyrites. It is presumably this fire that is mentioned by *William White*, who said: "Bradley Moor, a little to the South of Bilston, is remarkable for "a very extraordinary phenomenon called a *pseudo-volcano*, or *wild-fire*, which has "continued burning for the last seventy years. . . . What is likewise curious the "surface is sometimes covered with sulphur, for many yards, in such quantities as "to be easily gathered."† It is possible that White was here quoting from a much older work, as fifty years earlier the Bradley Moor fire was described in almost similar words.‡ *Dr. Wilkes* gives a full account of this occurrence in 1739.§

That practical mining men, as well as theorists, have for long been imbued with the idea that pyrites was intimately concerned with the origin of underground fires, is instanced by a paper written by *Robert Bald*, a Scottish mining engineer, which dealt with "Fires that take place in Collieries."‖ He said: "It has been a matter of "physical investigation to show by what chemical action spontaneous ignition is "generated in those coals where pyrites abound. Air and moisture seem to be "indispensably necessary; and it is also requisite that the coal rubbish be of "considerable thickness—for if it is only a foot or two in thickness, the decomposition "will take place with a very small degree of heat, but fire will not be the consequence.

"In this case, it appears that the heat is dissipated the instant it is formed; "whereas, when the heap is of several feet in thickness, there is a certain degree of "pressure, and the heat, as it is formed, accumulates. This accumulation of caloric "hastens the more rapid decomposition when heat is also more rapidly generated, "and that to the point when actual igition commences. The heat and fire which "are generated in wet hay seem to depend on similar circumstances, for, without "accumulation and pressure, actual fire will not take place.

"As to the chemical action, several principles may be acting, namely, the "decomposition of atmospheric air, when the iron of the pyrites seizes the oxygen of "the air, and sets the latent caloric free; the oxygen and hydrogen of the water may "highly contribute to increase the temperature; and we know that it is a common "occurrence for the coal rubbish, which is mixed with pyrites, at the mouth of pits, "to take fire from the same causes; but depth and pressure are always necessary to "produce the results."

During the period 1846–1850, three reports were presented to Parliament by *De La Beche and Playfair* on "Steam Coals for the Royal Navy." They made no definite statement controverting the pyrites theory, but the opinion was expressed that the presence of dust in stocks of coal was more likely to give rise to spontaneous combustion than the mere presence of pyrites.

The "pyrites" theory popularly upheld for a long period both before, and since, the time of Berzelius was first doubted by *Dr. John Percy* in a lecture given by him in 1864,¶ and the following extract from his book on "Metallurgy" published in 1875 is of peculiar interest. He said: "The coal in some collieries is apt to ignite "spontaneously when it is allowed to accumulate in the state of dust or fine slack, "either in the pit or out of it, or when ribs or pillars of coal are subjected to great "crushing weight; and perhaps no coal in Great Britain is more liable to such "ignition than the Ten-yard or Thick Coal of South Staffordshire. On the contrary, "in other collieries the spontaneous ignition of coal is generally unknown. I have "had the opportunity of personally inspecting a Thick-Coal pit immediately before "the outbreak of fire. The first unequivocal sign of incipient combustion is a peculiar "smell, termed 'fire-stink' by the colliers, which appeared to me to be precisely

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* Annals of Philosophy, or Magazine of Chemistry, Mineralogy, Mechanics, Natural History, Agriculture and the Arts, Vol. XI., January to June 1818, page 342, Article IV.

† History Gazetteer and Directory of Staffs and the City and County of Lichfield. By William White, 2nd Edition, 1851 (pages 138 and 139).

‡ The History and Antiquities of Staffordshire. Compiled from the manuscripts of Huntbach, Foxdale, Bishop Lyttelton, and other collections of Dr. Wilkes, the Rev. T. Fielde, &c., M.D.C.C.C.I., Vol. II., part I., page 172.

§ *Ibid*, page 85.

‖ The Edinburgh New Philosophical Journal, exhibiting a view of the Progressive Discoveries and Improvements in the Sciences and the Arts. Conducted by Robert Jameson. April–September 1828.

On the Fires that take place in Collieries; and particularly on the Recent Fires in the Whitehill and Polton Collieries in Mid-Lothian, and South Sauchie Colliery in Clackmannanshire.—By Robert Bald, Esq., Mining Engineer, F.R.S.E., M.W.S., etc. (page 120).

¶ Swiney Lect. Chem. Geol., Jan. 28, 1864; Chem. News, July 9, 1864, p. 19.

" similar to that which is produced by distilling coal at the lowest temperature at
" which decomposition commences.

" I came to the conclusion that such incipient decomposition had begun, and " conceived that it was due to the heat developed by the oxidation of accumulated " finely-divided coal, just as in the well-known case of a heap of oiled rags. There " was not the slightest odour of sulphuretted hydrogen, and no chemist requires to be " informed that that gas is not a product of the atmospheric oxidation of iron-pyrites.

" In a lecture delivered in 1864, I used these words when speaking about coal: " 'I am disposed to believe that there is another cause of spontaneous ignition (besides " 'iron-pyrites) similar to that which determines the spontaneous combustion of " 'cotton waste, namely, the absorption of oxygen by coal reduced to a fine state of " 'division;' and I had often previously stated the same view in my lectures at the " Royal School of Mines. I was led to this opinion mainly by the consideration of " the fact that the Ten-Yard coal contains only a small proportion of iron-pyrites, " usually not more than is equivalent to 0·5 per cent. of sulphur. I had also observed " in a part of the old workings of the colliery above referred to, a pretty copious " evolution of carbonic acid, which, near the ground, immediately extinguished a " lighted candle.

" Atmospheric oxidation of iron pyrites is always a comparatively slow process, " and, consequently, there must be much loss of heat. It is not, however, asserted " that iron pyrites may not, when present in coal in considerable quantity, develop " sufficient heat during its oxidation by atmospheric air to set the coal on fire.

" From what has been presented concerning the oxidation of coal, indications of " value for practical guidance in the working of coal liable to spontaneous ignition " may be derived. Increase of temperature greatly promotes oxidation, and in " proportion to the rapidity of oxidation is the elevation of the temperature and " consequent risk of combustion. The temperature of the pit should, therefore, be " kept as low as possible; but how, it may be asked, is this to be done? By a " vigorous current of cool air through the workings; but such a current can only be " obtained when the temperature of the external air is much lower than that of the " pit. When an outbreak of fire has been apprehended in a particular part of a " South Staffordshire Thick-coal colliery, the practice which I have seen was greatly " to reduce the current of air in that part; but, except when the temperature of the " external air exceeded that of the pit, the result would necessarily be elevation of " temperature, more rapid oxidation. If once combustion begins, an attempt should " be made to extinguish the fire by water notwithstanding such attempts may have " frequently failed, and to remove from the pit the coal in which it broke out; and if " this be impracticable, the only course to be taken is to dam up that part of the pit " and exclude air from it as much as possible."

In 1866 we find *Liebig*, the German chemist, holding the view that pyrites is the cause of spontaneous ignition (*Q.* 2738). Among the many investigators who were at work about this time should be included Fleck, Stein, Grundman, Varrentrays, Sauerwein, Regranlt, Monsilly, Thompson, and Reder, all of whose work and opinions tended to upset the theory, until then generally held, that pyrites was the primary cause of the self-heating of coal. They concentrated attention on the weathering of coals with consequent loss of carbon and hydrogen accompanied by an increase in oxygen.

But perhaps the work of *Dr. E. Richters*, Chemist in the Mining School of Waldenburg, was that chiefly instrumental in upsetting the earlier theory. The conclusions arrived at by Richters were alluded to by several of the witnesses who gave evidence before us, and are of such moment as to warrant our devoting some space to their consideration. Richters showed* that if powdered coal be heated at a temperature of from 180° to 200° C., the coal having been previously dried in a desiccator until its weight becomes constant, " an increase in weight soon becomes " apparent. For instance, according to the experiments which I have hitherto made, " after heating for 12 hours, the weight may increase by several per cent., in 20 hours " the increase of weight has reached its maximum, and any further heating then " produces a diminution in weight. Coal which has gained in weight resembles " unheated coal in little more than in appearance. The differences between heated " and unheated coal are:—

" (1) the heated coal has a greater specific gravity than the unheated;
" (2) the chemical constitution is different;
" (3) when heated to a red heat, it behaves differently from ordinary coal;
" (4) coal which has been heated abstracts moisture from the atmosphere much " more freely than the normal variety."

* His first paper was published in "Dingler's Polytechnisches Journal," Vol. 190, December 1868, and continued in Volumes 193 and 195 of the same journal.

Richters' second paper* contained an account of a series of experiments made on the absorption of oxygen by coal at temperatures between 15° and 21° C., each experiment lasting a week to ten days. He sums up the results as follows :—

"So much, however, follows from my observations with full certainty, namely, "that perfectly dry coal, as well as air-dried coal, is able to absorb oxygen without "exhaling carbon dioxide, both from dry air and from air saturated with water "vapour. I shall show in another communication that in this behaviour of coal "we have the key to the explanation of the whole series of phenomena, which "without this key can hardly be explained." To the possible contention that the oxygen might be absorbed by the pyrites and not by the coal substance he instances the fact of several coals which were "extraordinarily poor in pyrites absorbing "oxygen," and states that pyrites is quite unaltered in dry air, though in moist air "it does absorb a certain quantity of oxygen, but in very small proportions, so that if "we mix an indifferent substance—for instance, quartz sand—with the pyrites, so "as to make a mixture having the same pyrites content as the above-mentioned "coals, it appeared that, in the first case, no oxygen was absorbed, and in the "second only a very small quantity, even when the mixture was left for a long time "with a measured volume of air."

In the next paper† Richters states that "coal absorbs carbon dioxide with the "greatest readiness. The volume of this gas, which is taken up in a given time, "is often greater than three times the volume of oxygen which could be taken "up . . . ." "If coal which has been saturated with carbon "dioxide is boiled for half-an-hour in water and is then air-dried, so that it remains "saturated with hygroscopic moisture, it is found to have recovered its original "absorptive properties.

"Coal which has been exposed for a long time to the air, until it has lost its "power of absorbing oxygen, behaves in a completely different manner when the "foregoing experiments are performed upon it. For instance, when exposed under "the receiver of an air-pump it does not by any means recover its original power of "absorption, though this power is still partly restored by boiling out with water. "Carbon dioxide is either not absorbed at all by such coal, or in only very small "proportions." In this final paper Richters concluded that pyrites can have little or no effect on the spontaneous heating of the coal examined, thus confirming the views previously held by Percy and others.

In 1876 a *Royal Commission* appointed in Great Britain to inquire into the "*Spontaneous Combustion of Coal in Ships*" fell back on the old pyrites theory, though the Commissioners found also that condensation of oxygen on the surface of the coal and oxidation of the coal matter were contributory causes.

Haton de la Goupilliere stated in 1878 in his "*Rapport de la Commission d'études des moyens propres à prévenir les explosions de grisou*," that the cause of spontaneous heating lay in the coal itself, possibly assisted by the existence of pyrites and with the necessary presence of air.

After Richters, perhaps the most helpful of the earlier investigators was *Henri Fayol*, Engineer and Manager of the Commentry and Montvicq Collieries in Central France. Indeed his first series of researches may be regarded as an extension of Richters' experiments. In 1879 he published a pamphlet entitled "*Etudes sur l'alteration et la combustion spontanée de la houille exposé à l'air.*"

Fayol, who carried out his experiments on an exceptionally large scale, arrived at definite and important results. He declared that to preserve stocks of coal unaltered and without deterioration it was necessary to exclude the coal from the action of the air, a process best accomplished by its storage in air-tight receptacles or by its total immersion in water. He said, with further reference to his investigations on heaps of coal, that :—"(1) Where the layer of slack is thin there is no rise "in temperature ; (2) the temperature at any time increases with the height of the "heap, *i.e.*, as we pass along the heap from the lowest to the highest points there is "a continuous rise of temperature in the coal ; (3) at a height of 3 to 4 m. (10–13 ft.) "the temperature rises steadily at first and finally falls without ever passing 60° to "70° C. (140° to 158° F.); (4) at or about a height of 4 m. (13 ft.) the temperature "continues to rise."

Fayol next proceeded to investigate the theory that spontaneous combustion was to a certain extent promoted by the influence of moisture, summing up his experience in the statement that "the influence of wet weather on heaps of coal has not been "sufficiently marked to be observable." He investigated the possibility of pyrites being one of the causes of spontaneous combustion, but he was careful to guard

* *Ibid*, Vol. 193, page 51 July 1869. † *Ibid*, Vol. 315, page 193, 1870.

himself against any generalisation of the result obtained, although he did find that the cases of spontaneous firing under his experimental conditions were independent of the quantity of pyrites present.

Since the date of Fayol's experiments other investigators have continued on similar lines, but some of them, including *Haedicke** in 1881 and *Lewes*† in 1890, came to the conclusion that pyrites was either a primary or at least an important cause in the self-heating of coal.

Two *Royal Commissions on "Ships Carrying Coals"* were appointed in New South Wales and sat at Sydney from 1896 to 1900. The results of the investigations then made confirmed the conclusions arrived at by Fayol in 1879 with regard to the importance of the question of the depth of storage piles. They also established the main principles relative to the cause of spontaneous combustion of coal cargoes, which, important though they are, have not a direct bearing on the problem with which we are immediately concerned.

In 1898 *Messrs. Haldane and Meachem* carried out extensive experiments at Hamstead Colliery, South Staffordshire, and showed that:—

(i) The rate of absorption of oxygen by coal varies directly with the percentage of oxygen present in the air;

(ii) The rate of absorption of oxygen is doubled for every 30° C. rise of temperature;

(iii) The rate of absorption of oxygen decreases as time goes on;

(iv) Absorption goes on at the coal surface and does not penetrate very deeply.

The results contained in the report of the *Oberschlesische Grubenbrand Commission on Spontaneous Combustion in Coal Mines*, issued in 1910, are very valuable. The important facts and conclusions emerging from this inquiry may be epitomised as follows:—

(1) Thickness of Seam.—The seams in Upper Silesia which are particularly liable to spontaneous combustion are, almost exclusively, those of the Saddle Group which are characterised by their great thickness. The critical thickness is about 4 metres (13 feet) "Whenever a fire breaks out "in seams of lesser thickness, this is generally attributable to special "causes."

(2) Composition of Coal.—If the chemicals contained in the coal play an important part in spontaneous combustion, no definite conclusion can at present be drawn from the analysis as to what mixtures of chemical combinations specially contribute to the spontaneous ignition or combustion of coal.

(3) Absorption of Oxygen.—All solid bodies are probably more or less capable of attracting and condensing oxygen from the atmosphere and of surface absorption of the gas. This really mechanical process produces heat, which again increases the tendency to surface absorption of oxygen. This alternative action, in conjunction with the fact that the condensed oxygen is particularly liable to enter into chemical combination with the material, thus generating further heat, accounts for the possibility of heating the material in question to such an extent that under certain conditions spontaneous combustion may take place.

(4) Oxidising Surface.—The greater the surface exposed to the air per cubic measurement, that is to say, the smaller the intervening spaces, the greater the risk of spontaneous combustion. For this reason a heap of hard large coal stacked above ground, the surface area of which is not increased to any extent by breaking up the coal, will hardly ever ignite, while a heap of small coal of the same chemical composition and occupying the same amount of room may ignite very easily when the surface area exposed to the air is comparatively large, and the air current comparatively smaller, in consequence of the greater or smaller obstruction of the air channels.

(5) Moisture.—Moisture is an important factor in spontaneous combustion; the Commissioners say that "this is not always sufficiently appreciated. It "has been proved that merely small quantities of water cause an increased

* "Zur Selbstentzündung der Steinkohle." Dingler's Poly. Journ., Vol. 239, 1881, pp. 148–149.
† "Spontaneous Ignition of Coal Cargoes." Trans. Inst. Naval Architects, Vol. XXXI., 1890, pp. 204–228.

" burning of a coal heap, and that most fires in coal stacks occur after " rain. On the other hand, a stack of coal which has become ignited can " be extinguished, if entirely covered with water. It is a fact that Lignose " (Ligno Cellulose), which is the basis of coal, constantly decomposes " under the action of slight moisture, that is to say, it is slowly consumed, " whilst wood which is permanently covered by water retains, for some " time, its molecular structure."

(6) Pyrites.—" A less important factor in the spontaneous combustion is " found in the action of white iron pyrites (marcasite), the oxidising heat " of which had, for some time, been considered in Upper Silesia as " the definite reason of the burning of coal. Richters has shown that by " the oxidation of sulphur which—as far as Upper Silesia is concerned— " forms only about 1 per cent. of the coal, a rise of temperature of only " 72° C. can be caused, and this increase of temperature is of course not " sufficient to ignite the coal. There is no doubt that white iron pyrites " in course of decomposition—particularly if moisture be present—will " contribute to a large extent to the spontaneous combustion of coal in so " far as the heat created by oxidation increases the absorbing power of " the coal surface for oxygen."

(7) Effect of Ventilation.—The danger of spontaneous combustion is inconsiderable in wide level galleries through which air currents pass freely.

(8) Danger from Stoppage of Working.—If it is not impossible for fires in mines to originate by spontaneous combustion in galleries during actual work, it is all the more probable that coal will ignite in galleries which remain unworked for months and years. There is peculiar danger of fire breaking out openly when such galleries are being worked after a long period if the work does not proceed rapidly.

(9) Timbering.—It is advisable that timbering of every description should be taken down and removed, as far as possible, after it has served its purpose, inasmuch as in dry workings mine timber in particular may ignite and thus contribute to the spreading of the fire with increased production of carbon monoxide.

(10) Gobbing.—The Commissioners consider that "gobbing" or stowing the waste is a practical means of preventing mine fires. It is an excellent way of ensuring clean working, so that as little coal as possible remains behind in the old working; it fills up the excavated pillars and galleries and thus prevents the access of air; by filling up the cavities from which coal has been taken, it withstands the falling-in tendencies of the ground and the consequent increase of temperature from the effect of pressure and friction.

SECTION II.

THE PROBABLE CAUSE OR CAUSES FROM THE SCIENTIFIC POINT OF VIEW OF THE INITIATION OF SPONTANEOUS COMBUSTION OF COAL IN MINES.

We have alluded in the preceding pages to the views and theories held at different periods with reference to the conditions which were accountable for the spontaneous combustion of coal, as to which much dubiety appears to have been consistently present in the minds of mining men. With the object of arriving at a correct understanding on this point, we heard evidence from a number of eminent scientists who had specially studied the subject—evidence as to the chemical processes or physical conditions which induce or conduce to what is known as "spontaneous combustion" of coal, a phenomenon which may be defined as the heating of coal by means other than the artificial application of heat.

(1) *The bearing on the subject of the Physical and Chemical Structure of Coal.*

The structure of coal has an important bearing on the subject of spontaneous combustion, and much credit is due to Mr. Lomax and Dr. Marie Stopes for the original research they have separately carried out in this respect. Both of these palæobotanists gave evidence before us.* The view commonly held by scientists and others since the time of Huxley, that coal of the Coal Measure period is the result of the fossilization mainly of the tissue and the spores of giant club-mosses and ferns, is found to be only partially correct. The remains of these plants undoubtedly enter largely into the formation of coal, and that true wood also flourished in the Coal Measure period is proved by the fact that *Cordaites* is one of the commonest plants in the Coal Measures, one of the chief species being *Cordaites principalis* (*Q.* 13,116). These were true woody trees from 40 to 60 feet high. Indeed, the plants forming the coal had a large proportion of ordinary wood, *ligno cellulose*, in their composition. From the point of view of our inquiry, the bearing of this is important only from the fact that "fusain" (*see* later) is almost entirely composed of wood fibres. Dr. Stopes said she "had still to be shown a fragment or portion " of fusain which is not wood, except one leaf specimen which I was shown in " America. I have not observed one example of fusain in this country of which the " plant was anything but woody fibres, and I have handled a large quantity of " fusain" (*Q.* 13,119). Coal contains two main types of compounds: the one (humic) apparently derived from various celluloses which entered into the composition of the plants forming the coal, and the other of a resinous nature, presumably derived from some resinous substances comprised in the coal forming plants (*Q.* 13,125).

Huxley described† the microscopical structure of the Better Bed Coal of Yorkshire which he found to consist almost wholly of the "spores" of Lycopodiaceous plants. Other coal-seams, however, are of different constitution and in consequence yield a different quality of coal. Indeed many seams, particularly the thicker ones, are formed of alternating layers of spore coal, humic coal, fusain, etc., according as the woody tissue derived from stems or leaves or the reproductive organs (all in varying stages of decomposition) may predominate. Thus seams may be characterised by the relative abundance or absence of bands of smut, or spore coal, but the main mass of almost all of our English coal seams may be regarded as consisting of the vegetative parts of plants which flourished in the Coal Measure age.

Dr. Marie Stopes has given distinctive names to the ingredients of coal, represented by its banded structure, as follows (*Q.* 13,019–20):—

Fusain—the equivalent of "mother-of-coal," mineral charcoal, "dant," "smut," etc.

Durain—the equivalent of the "dull," hard coal of various authors; the "*mattkohle*" of the Germans.

Clarain—Banded with bright lustre.
Vitrain—Conchoidal fracture; brilliant in appearance.
{ together, the equivalent of the "bright" or "glance" coal of various authors; the "*glanzkohle*" of the Germans.

These ingredients, which may be in close juxtaposition in the same block of coal, have been chemically examined at the Home Office Experimental Station and found to differ markedly in chemical composition and in their behaviour towards re-agents. Thus, in one case, whereas in the vitrain the proportion extracted by pyridine was 34·4 per cent., in the durain it was only 21·6 per cent. (*Q.* 13,020); *see also* Professor Bedson's evidence (*Q.* 2660–1). Again, the moisture content was different, that of the vitrain being 12·6 per cent., whereas that of the durain was only 6·5 per cent.; of these four substances the fusain is the most readily oxidised at a low temperature (15° C.), but at a higher temperature (50° C.) the vitrain is the most rapidly oxidised. *Dr. Wheeler and Dr. Stopes* came to the conclusion "that the " critical point in any piece of coal is the juncture between vitrain and fusain, and " that the fusain is the touch which sets the vitrain on fire" (*Q.* 13,022). In their opinion it is particularly dangerous "if the fusain is found embedded in the vitrain. " When you find the fusain and vitrain in juxtaposition the fusain is most often not " in the form of layers in the vitrain but in pockets."

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* 15th and 20th Days (*Q.* 8373–8763 and 11,398–11,611) and 24th Day (*Q.* 13,057–13,165).

† *The Contemporary Review*: Vol. XV. (1870), pp. 618–629.

The general conclusions drawn by *Dr. Wheeler* and *Dr. Stopes* from the tests which they have conducted are : "(1) Of the three main ingredients of the banded " coal, the bright ones, vitrain and clarain, show greater liability to oxidise and " ignite than the dull durain ; (2) the influence of fusain is uncertain. The results " . . . . point to its being improbable that fusain has a preponderating influence " in determining the actual ignition of the coal after self-heating has begun ; but it " is conceivable that the rapid absorption of oxygen by fusain at low temperatures " may be attended by a sufficient evolution of heat to raise appreciably the tempera- " ture of the main mass of coal, thereby causing the most inflammable ingredient " (vitrain) to react more rapidly with oxygen. In other words, the juncture of fusain " with vitrain appears to be critical " (*Q.* 13,036).

Mr. F. S. Sinnatt, at the Lancashire and Cheshire Coal Research Laboratory at Manchester, has determined that what is familiarly known as " mother-of-coal," or the dull coal dust found in seams, is chiefly composed of fusain. He found, too, that fusain consisted of at least two substances, one containing more sulphur than the other ; one specimen examined contained 6 per cent. of sulphur as against 2 per cent. in the remainder. Fusain " has the property of absorbing liquids, and probably " gases also " ; this may be due to its physical state, for it occurs in the seam as a porous, spongy, flocculent powder, and consequently exposes to the air a much greater surface than does the less porous coal. Its state is, therefore, such as facilitates absorption of oxygen, and, consequently, Mr. Sinnatt argued, such as to render it likely to be the seat of spontaneous combustion in a seam. Again, he determined that fusain is the chief constituent of the coal dust in mines, and that if some coal be crushed, the portion which passes through a fine mesh is mostly fusain and has the peculiarity that it will ignite and glow at a lower temperature than the portion which only passes through a less fine mesh ; further, that with a mixture of fine and less fine coal dust, the introduction of even a small proportion of the fine material brings the combustion point of the mixture to a much lower temperature than that of the coarse material alone. In evidence of the low ignition point of fusain, this witness lighted a small heap of dust piled in the form of a cone. In two or three minutes the mass was alight, burning slowly downwards with a dull red glow scarcely visible in daylight, and emitting a faint odour resembling " gob-stink," while in about 10 minutes the small pile was consumed. Mr. Rigby (a member of this Committee) produced the same result from impalpably fine coal dust which had been collected from the timbers in the main roads of the Eight-Feet Banbury Seam at Bunker's Hill Colliery, North Staffordshire, in 1875, and preserved in a sealed jar for 45 years.

From a microscopical examination of coal taken from a number of seams, *Mr. Lomax* concludes that the vegetable débris in the bottom portion of coal seams is derived from very lowly plants, and that these formed the *humus* in which a higher class of plants could and did grow ; " as you rise in the seam, the organisation of the " higher class of plants gradually rises too " (*Q.* 8436). The lycopods and their spores are most in evidence in the higher portions of a seam (*Q.* 8457), and as we ascend in the seam the spores become larger and the lycopods more exuberant and stronger.

Mr. Lomax observed in seams minute spherical bodies which he named " globulites." In some portions of a seam they exist in great quantities. These bodies are hard to detect in freshly won coal, but swell on contact with the oxygen of the air, and " they are more or less zonal or concretional." As to their origin he is doubtful ; he thought that they might have originated from some sort of decay in the vegetable débris, or might be of animal origin, but after studying a great many sections, his later belief is that they are composed of inorganic matter, and are " the " commencement, through the decay of vegetable matter, of the formation of iron." On being asked, " Then would one be right in putting it in this way, that decaying " vegetable matter has the property of converting the iron in its composition into " something which seems to have a core of iron pyrites ? " he replied : " Yes, or can " have a fringe of iron pyrites " (*Q.* 8572). Again, to the question : " Have you " formed any theory as to what leads on to the spontaneous combustion of coal ? Do " you think that these globulites which seem to be so unstable may in their change " produce a certain amount of initial heat, and that the resinous matter which is " in conjunction with them would then become altered and absorb oxygen at a great " rate ? " he replied, " Yes." It may be, of course, that on their decomposition these bodies tend to break up the coal and lay it open for oxidation (*Q.* 8646.)

The importance of this discovery is obvious and might go far to explain the cause of initial heating of coal, if, as the result of further and detailed investigation, it is

found that these apparently unstable bodies represent minute specks of marcasite which when exposed to the air are subject to rapid decomposition, and, further, that seams subject to spontaneous combustion are characterised by the presence of these globulites in large quantities and that in seams immune from self-heating they are either absent or are only sparsely present.

(2) *The possibility of the self-heating of Coal being initiated by Bacterial Action.*

By some writers, the initial stage of the self-heating of coal has been attributed to the agency of bacteria, and the well-known phenomenon of self-heating of hay-stacks and dung-hills under certain conditions of dampness, etc., which is explained as being due to a process of bacterial fermentation, has been advanced in support of the contention that the self-heating of coal is attributable to bacterial agency. We have therefore deemed it advisable to investigate the subject from this point of view and have ascertained the views thereon of the various scientific experts who appeared before us.

The evidence of *Dr. Haldane*, the well-known physiologist, was of peculiar interest. He explained that the initial heating of a wet haystack is, as far as is known, a process of fermentation due to bacteria. "Then if you cut into that haystack and " just introduce a moderate amount of air—not too much—the thing will fire and go " into a blaze." The actual cause of the fire is a purely chemical process : "probably " when the bacteria do not get enough of oxygen they produce substances which will " oxidise easily, and if you suddenly let in the oxygen to those substances the thing " heats up." He thought that "there might be a process like that in the coal." (*Q.* 7092–7109 inclusive). This evidence was given in April 1914, and Dr. Haldane felt that the subject was of such importance as to warrant further investigation.

Nearly a year later (February 1915) *Mr. Winmill*, Dr. Haldane's Chief Assistant at the Doncaster Laboratory, gave evidence before us, and in describing the experiments conducted by him on the self-heating of coal, (*see* page 25) and in explaining the curves showing the rate of oxidation, he said : "The curves are somewhat remarkable in " form, as they show comparatively an enormous rate of oxidation initially, which, " however, falls off rapidly as time goes on. This is just the reverse of what would " be expected if the action were bacterial" (*Q.* 11,080).

Mr. J. I. Graham, one of Mr. Winmill's assistants, determined the rate of oxidation of coal after it had been subjected to a temperature of 100° C. *in vacuo* for 20 hours (a temperature which would completely exterminate all bacteria), and he found that the rate of oxidation was quite unaffected by the sterilization.

These facts appear to us conclusive evidence against the bacterial action theory as applied to the self-heating of coal.

A reason from the practical mining point of view, which was put forward by Mr. Winmill, may also be quoted. He said : "I have measured the temperature up " to 50 yards in completely closed goaves over a period of over six months, and in " every case I found the temperature rose to that of the strata fairly quietly, and then " remained constant. Coal cannot therefore store oxygen when it is first exposed to " the air, and so retain a store of oxygen for the action of bacteria in the goaves. " Coal does absorb oxygen, but it is quite clear that that oxygen cannot feed bacteria " in the goaves . . . because there is no rise in temperature. . . . Bacterial " action must produce heat ; it cannot go on without producing heat" (*Q.* 10,750—10,759 inclusive).

If bacteria had anything to do with the initial heating of coal the presence of moisture would be of importance (*Q.* 7151).

(3) *The Effect of the Moisture Content of Coal in respect of Self-heating.*

Although *Dr. Wheeler* informed us that he had made some experiments which seemed to show that moist coal does not absorb oxygen as readily as dry coal, he stated that he would not like to say definitely that moisture has no effect (*Q.* 2540).

Professor Bone, in describing the experiments of Parr and Kressman in America, stated that these experimenters had found that "in coal, with conditions otherwise " favourable to oxidation, the oxidation will be facilitated by moisture" (*Q.* 3291). Asked whether by moisture, external moisture or moisture of composition was meant, he replied : "Either, I gather from their conclusion ; and if the coal is thoroughly " wetted for instance, as it was in their experiments, they say, 'without exception in " 'all the series of tests, the wetting of the coal increased the activity as shown by

" 'the ultimate temperature.' " (*Q.*) "So that you would gather, supposing that " coal contained such a high percentage of moisture—I mean dry coal—as, say, 8 per " cent. (as we know some coals do in this country), other things being equal, that " would be more liable to spontaneous combustion than a coal containing 2 or 3 per " cent. of moisture?"—(*A.*) "I should say so, judging from these experiments," but he added that he would not like to pronounce a final opinion on the point, and suggested further experimental investigation.

The position was well put by *Mr. Winmill*, who said in his evidence: "There " are many conflicting statements as to the effect of moisture on the rate of oxidation " of coal and on the rate of heating. In this case the water may play a double role. " It may accelerate or retard the rate of oxidation, but it must in general retard the " rate of heating, for, since the water is volatile, coal cannot heat above 100° centigrade " without evaporation of its moisture at the expense of a considerable quantity of " heat. . . . . Experiments made by Mr. Graham in his laboratory, show con- " clusively that 'moist' coal oxidises more readily than dry, and this is in accordance " with general chemical theory" (*Q.* 10,759).* He found that "moist coal absorbs " oxygen 50 per cent. faster than dry coal," the word "moist" being used in the chemical as opposed to the physical sense. If this is true, why should a coal of high moisture content absorb oxygen more readily than a coal of low moisture content? What is the chemical reaction that takes place? No reason was given us and we are unable to advance one, unless that which we give at the end of this section of our Report is deemed a satisfactory explanation.

It is an interesting fact that in Durham, where spontaneous combustion in mines is practically unknown, the coals are extremely low in moisture content, whereas in South Staffordshire, where spontaneous combustion is perhaps more common than anywhere in the world, the coals are very high in moisture content. The Silesian coals are also very high in hygroscopic moisture, and are very liable to spontaneous combustion. One possible explanation of this effect may be found as the result of the experiments conducted by Mr. F. S. Sinnatt (*Q.* 13,209). He and one of his students carried out systematic experiments on the relationship between the moisture in the coal and the humidity of the air. These indicated that when the humidity of the atmosphere rose, so did the moisture content of the coal. Most South Staffordshire coals are of a highly porous nature, vastly more so than nearly all Durham coals. Their relative friability or weathering properties may be illustrated by the fact that if samples of them be placed in beakers in a room, the Durham coal will at the end of a year be intact, while the South Staffordshire coal will have crumbled into dust. It has occurred to us, therefore, that the South Staffordshire variety, because of its highly porous nature, has a high moisture content and the process of moisture breathing (rise and fall of moisture content) proves it also to be more permeable to the oxygen in the air. If this is so, moisture content is simply a measure of porosity, and it follows that the more porous a coal is, the greater is the area exposed to oxidation. But this would not explain the effect of external wetting in increasing the heating of coal.

(4) *The effect of the presence of Pyrites in Coal.*

Iron pyrites, or iron disulphide, occurs in coal seams in several forms and in varying quantities. Sometimes it occurs in the form of bands, intermixed with shale or dirt or coal; sometimes as nodules or crystals (cubical); sometimes as marcasite (the rhombic form), which is less stable than the cubical form; but even among marcasites themselves, as Threlfall has pointed out, there are great differences in stability, "the fibrous brasses, for instance, being possibly less stable than the lamellæ " of pyrites found in most coals. Again, pyrites occurs as an amorphous powder " disseminated throughout the coal substance as minute specks, and it occurs in a " fourth form, in which the pyrites has taken the place of organic tissues in the same " way as carbonates have done." What determines the relative stability of the different forms of pyrites has not yet been ascertained, and we were unable to obtain enlightenment from any of the scientists who appeared before us.

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* The view expressed by the late Prof. Vivian B. Lewes in his work on the "Carbonisation of Coal" (p. 25) is interesting in this connection. He wrote: "Moisture has a most remarkable effect upon the " spontaneous ignition of coal. The absorption of oxygen is at first retarded by external wetting, but " after a time the presence of moisture accelerates the action of the absorbed oxygen upon the coal, and so " causes a serious increase of heat. The researches of Cooper, Baker and Dixon, and others, have of late " years so fully shown the important part which moisture plays in actions of this kind, that it is now " recognised as a most important factor."

With regard to the presence of pyrites in coal and its bearing on the questions before us, we set out to determine :—

(*a*) Whether pyrites is the primary cause of the self-heating of coal ;

(*b*) If not the primary cause, what part, if any, does it play in contributing to the cause of self-heating of coal.

Dr. Bedson, Professor of Chemistry at Armstrong College, said, alluding to pyrites, "of course, it is regarded as the prime factor by many . . . . by "some scientific men too . . . . I have always looked upon the pyrites "idea as being explained by the fact that the change which takes place in pyrites is "a change which you can see. The alteration in the appearance is a change which "you can follow with the eye, and that has rather fastened people's attention on it ; "whereas the alteration—the composition of the coal substance—is one which you "cannot see, it is one which you can only come to grips with when you have analysed "the coal before and after" (*Q*. 2738).

Dr. Wheeler, Chief Chemist at the Home Office Experimental Station, was in agreement with the well-known views of Threlfall, Richters and Fayol, to the effect that the self-heating of coal is not due, necessarily, to the presence of pyrites, but he was of opinion that the effect of moisture on coal containing a considerable proportion of pyrites would be to cause the coal to split up into small fragments, and so present a greater surface to oxidation, the cause of heating being the actual combination of oxygen with the coal substance. Dr. Wheeler said : "I should say it is unnecessary "to assume that pyrites is the cause of the spontaneous combustion of coal, because "you have a sufficient cause in the oxidation of the coal itself. If you eliminated the "pyrites you would still have the liability to spontaneous combustion."

Dr. Haldane, on the other hand, was not so definite. He stated that in the experiments of his assistant, Mr. Winmill, carried out at the Doncaster Laboratory, pyrites was shown to have practically no bearing on the absorption of oxygen by coal, but he added that "whatever pyrites has to do with spontaneous combustion, it is only "one cause amongst several." He did not think that it was realised how very variable pyrites is as regards its oxidisability. It was either Fayol or Richters who had made an experiment with pyrites by putting some into a flask for the purpose of determining whether it was liable to oxidation, and found that there was none ; "nor would there "be if he took a sample from a museum, because all the museum samples are "survivals of the least oxidisable form." We learned from this witness that the pyrites in the Bullhurst Seam of North Staffordshire—a seam very prone to spontaneous combustion—is very oxidisable. On the other hand, although some parts of the Barnsley Bed of Yorkshire are also very liable to spontaneous combustion, yet that part on the rise side of the South Yorkshire Field is immune from gob-fires, although a portion of the seam called the "clay" seam contains a fairly high percentage of pyrites. Again, the pyrites in the Barnsley Bed at Bentley Colliery (a colliery very subject to spontaneous combustion) oxidises very slowly. As Dr. Haldane remarked, it remains apparently unaffected by air for months. He instanced a case where pyrites—but it was copper pyrites—heated to such an extent that the pyrites burned. This was in a metal mine (*Q*. 7520).

We invited *Mr.* Richard Threlfall*, F.R.S., who was a Member of the Royal Commissions which sat at Sydney, New South Wales, from 1896 to 1900,† to appear before us, but he stated that his views had been fully set out in an address which he delivered on April 1st, 1909, to the Birmingham Section of the Society of Chemical Industry, entitled "The Spontaneous Heating of Coal particularly during Shipment," copies of which he kindly supplied and to which, he said, he had nothing to add.

The earliest indication that we have been able to discover of the belief in the variability of pyrites in coal in respect of oxidation is that of *Threlfall*. He stated in his address that "the stability of iron disulphide as it occurs in coal is probably a "very variable quantity, and it would be worth while to make a comparative study of "the matter so as to obtain precise data which at present are lacking. We have "already seen that neither Richters nor Fayol were able to detect any effect as regards "the oxidation of their respective coals by their respective samples of pyrites, but it "may be argued that had they happened to use coal brasses of South Staffordshire "for instance, the results would have been different."

The summing up of the case against pyrites, by which Threlfall arrives at the conclusion that the self-heating of coal is not due to, nor in the main caused by,

* Now Sir Richard Threlfall, K.B.E., F.R.S.

† *Vide* page 11.

the oxidation of the iron pyrites diffused through the coal substance, is so cogent and, in our opinion, so admirably sums up the position that we deem it well to quote it at some length. He says : " Given a mixture of coal and pyrites both oxidisable in " air and both reactions being accompanied by the evolution of heat, it is of course " impossible to demonstrate that a spontaneous fire in such a mixture should not " have been assisted by the presence of pyrites. Some considerations appearing " below show, however, that it is in general unlikely that the presence or absence " of pyrites has any appreciable influence . . . . . .

" We have to fall back on general principles, and from these it appears that " coal cargoes seldom or never fire through the action of pyrites, and for the " following reasons :—

" 1. The cases of spontaneous firing under experimental conditions observed " by Fayol were found to be independent of the quantity of pyrites " present.

" 2. The laboratory experiments of Richters, so far as they go, lead to the same " result—though an entirely different coal was used.

" 3. Experience shows that pyrites is generally stable in air, *i.e.*, unless liquid " air is present. But it will be shown that spontaneous fires have often, " indeed generally, occurred in cargoes of dry, warm coal.

" 4. No connection has ever been traced between the pyrites content of coal " and the frequency of fires. The N.S.W. Commission No. 1 made " every effort to bring such an effect to light assuming it to exist, and " did not succeed in doing so, in fact the data were such as to indicate " that no relation existed.

" 5. In Commentry Coal, proved by Fayol to fire as a result of direct oxidation, " it was found that a mixture of fragments and dust was the most " dangerous, *i.e.*, would fire sooner under favourable conditions than any " other screen gradings of the same coal. But such a mixture is formed " in a coal cargo under the hatchways and nowhere else, and is produced " by the breakage of the coal in loading where it is dropped down the " hatchways under conditions which allow the large pieces to roll away " and the dust and slack to form a heap. The N.S.W. Commission No. 1 " obtained a considerable body of reliable evidence as to where fires " originated in coal cargoes, and discovered that they invariably started " under one of the hatchways. Similar evidence convinced the Royal " Commission of 1876 of the same fact. The spontaneous heating of " coal at sea therefore occurs under exactly the same physical conditions " as determined inflammation in Fayol's experiments—and in the latter " the influence of pyrites was inappreciable. It is difficult to believe, " therefore, that pyrites can have much effect in one of these entirely " parallel cases when its influence is known to have been negligible in " the other.

" 6. The way in which the temperature rises, *i.e.*, the temperature time curve " of a spontaneous fire at sea, has been often, though roughly, ascertained " by means of thermometers. Fayol and the Second N.S.W. Commission, " however, have recorded the same phenomenon in the experiments on " heaps, and the general progress of the heating is the same in both " cases. It would be strange if one referred to pyrites and the other " to the direct oxidation of coal.

" 7. Fayol states that 'the influence of wet weather on heaps of coal has not " ' been sufficiently marked to be observable, but if pyrites of all ordinary " ' varieties had come in question as a source of heating there is no " ' doubt that wet weather would have helped the heating. The N.S.W. " ' Commission No. 2 definitely proved that wetting 250 tons of coal " ' containing 0·5 per cent. sulphur, mainly as pyrites, prevented it from " ' rising above 40°-50° C., while 250 tons of dry coal of exactly the same " ' kind exposed under exactly similar circumstances rose to 135° C. in " ' about six weeks, and was only kept from firing by digging out.'

" 8. The spoil heaps in mines, often containing a great deal of pyrites, in some " cases nearly as much pyrites as coal, so far as I am informed, generally " fire where they are dry, not where they are damp. This at least has

"been true of the limited number of cases which have come to my notice;
"cases of firing in pillars also occur where the coal is dry.

"9. It was suggested by Sir Frederick Abel and Dr. Percy in the memorandum "prepared for the Royal Commission, 1876, that pyrites might have "some influence in promoting the disintegration of the coal if the cargo "was wet, and thus in preparing it mechanically for spontaneous heating. "This is true, but as fires start under hatchways where the coal is broken "by impact in any case to a far higher degree than it could be broken by "pyrites—it is clear that the above suggestion has no real application.

"Perhaps we may sum up the matter with the remark that a "sufficiently formidable array of evidence can be collected in favour of "Richters' view as to the origin of spontaneous fires to justify us in "neglecting the influence of pyrites in forming a general theory of "spontaneous combustion."

Admirable and cogent as this reasoning is, it might be regarded as almost conclusive in the elimination of pyrites as the primary cause of self-heating of coal but for the following facts.

Instances are forthcoming pointing to the effect of moisture on coal and refuse heaps of carbonaceous matter in raising the temperature and, in many instances, resulting in the outbreak of fire. Thus one of our late members, Mr. C. E. Rhodes, stated when examining Dr. Wheeler that "it is an undoubted fact that we (in "Yorkshire) never have any trouble with these burning muck heaps, except when we "have rain. When we have continued dry weather they dry up to all intents and "purposes, and there is no sign of any heat. As soon as ever you get rain you begin "to get heating up and bursting into flame again" (*Q.* 2537).

In the experiments of Mr. Lamplough and Miss Hill the pyrites in a sample of pyritic coal was separated as far as possible from the coal, and oxidised rapidly with the evolution of considerable heat. It would appear that neither Richters nor Fayol realised the important fact that great difference exists in the relative oxidisability of different forms of pyrites in coal, some forms being rapidly converted into sulphate of iron, others being practically immune from oxidation, the crystals remaining bright and defined for many years.

Though *Professor Bone* regarded the pyrites in the coal substance as not being the primary cause of self-heating, yet he agreed with *Parr and Kressman*, the American investigators, that it was a subsidiary cause. Their experiments, which he explained to us and commented upon, were made with wet and with dry Illinois coals—coals which are characterised by a high moisture content—(from 12 to 15 per cent.), and also a high pyritic content (the sulphur averaging about 4 per cent.). A series of fifteen experiments was made, "the first six with the object of ascertaining how far "the varying content of pyrites would affect the rise in temperature observed, and "also of judging at the same time the effect of wetting the coal. The coals were first "dried, then wetted again." The results showed in Professor Bone's opinion that—

(*a*) the rise of temperature was greater the more finely the coal was divided;

(*b*) in the case of series 3 and 4, in which 3 per cent. of pyritic coal was used, there was a more marked tendency or liability of a coal to ignite spontaneously after it had been wetted; that is to say, the wet coal showed a greater tendency to ignite spontaneously than the same coal in the dry state;

(*c*) series 5 and 6, with 5 per cent. of pyrites, led the experimenters to the conclusion that while the presence of pyrites is not essential to the spontaneous oxidation of coal, yet it is a factor (*Q.* 3284–5).

Messrs. Parr and Kressman arrived at this general conclusion; they said: "Since "the above experiments show that the oxidation of the pyrite is practically constant, "that is, about one-fifth of the total pyrite present, then it follows that coals with "increasing pyrite contents will have a corresponding increase in pyritic oxidation "and a correspondingly greater amount of heat will be liberated. . . . . It is to "be remembered, of course, that in actual storage the pyritic oxidation will proceed "much further than one-fifth of the total pyrite present, as in these particular "experiments, but the fact still remains that the degree of pyritic oxidation in coals "of various pyritic content is in direct proportion to the pyritic content, so long as "similar conditions of storage are maintained."

It does not seem to us that these experiments demonstrate that pyrites is even a cause contributory to spontaneous combustion of coal. They point to a certain rise of temperature due to the presence of pyrites, but they do not determine the extent of the rise due to oxidation of the pyrites alone and of the coal substance alone. In our opinion the only practical way definitely to determine the proportionate parts played by pyrites and by the coal substance in the self-heating of coal is to experiment on a coal well-known for its liability to self-heating, separating therefrom the pyritic content and determining the relative rates of oxidation and heating of (*a*) the pyritic content; (*b*) the coal substance. Experiments to this end have been carried out by Lamplough and Hill, by Winmill, and, at our suggestion, quite recently by Dr. Wheeler.

Mr. Winmill, who carried out elaborate experiments on the rate of heating of coal from the Barnsley Bed (Doncaster District) which he described in detail, was emphatic on the point that pyrites does not, in the first stage, heat more rapidly than coal. Even granting that certain forms of iron pyrites are liable to more or less rapid oxidation and consequent heating, the percentage of pyrites in the coal is very small, usually not more than 2 or 3 per cent., consequently the heat effect would be small and limited as compared with the heat due to the absorption of oxygen by the coal substance.

Since he gave evidence before us Mr. Winmill has re-determined Lamplough and Hill's rise of temperature values very accurately, and found 4·3 calories per cubic centimetre of oxygen absorbed for pyrites, and 2·1 calories for coal. He then determined the rates of oxidation of different kinds of pyrites and showed that there are wide differences dependent upon the physical conditions of the pyrites, while grinding the different kinds of pyrites apparently reduced them all to about the same level, thus :—

Sample.	A.	B.	C.	D.
Oxygen absorbed in 96 hours, c.c. -	1,065	853	913	53
,, ,, ,, 168 hours, c.c. -	1,670	—	1,383	—

"A" and "B" were the same sample of pyrites from the Bullhurst Seam containing 80 per cent. FeS_2, "A" having passed through a 60-mesh screen and "B" through a 10-mesh and remained on a 30-mesh. Samples "C" and "D" were a very stable pyrites from the Barnsley Bed and contained 98 per cent. FeS_2, "C" having passed through a 200-mesh screen and "D" through a 10-mesh and remained on a 30-mesh. The evidence that grinding reduces the difference in rate of oxidation is obvious.

Mr. Winmill calculated that a sample of pure pyrites can self-heat from 30° C. to 90° C. in 3 hours, as against 48 hours required by the average bituminous coal. This explained some rapid ignitions of small heaps of coal in North Staffordshire. In the presence of much other material, however, the effect of the pyrites is masked.

He found that one coal (Bullhurst, North Staffordshire) had such a low rate of oxidation when pure, or when containing its usual amount of pyrites, as to show that it could not self-heat. Yet the seam from which the coal was derived is perhaps more liable to spontaneous combustion than any other coal in that district. It is liable to contain in patches a high percentage of pyrites in a finely divided state mixed with the coal. The inference is that the initial impulse to self-heating must be given at these patches with high pyrites content.

With a view to clearing up some doubts which we had, on the part played by pyrites in the self-heating of coal, we asked Dr. Wheeler to carry out for us some experiments as to the rate of heating of samples of coal and pyrites taken from (1) the Bullhurst Seam at the Minnie Pit of North Staffordshire, and (2) the Barnsley Seam of Brodsworth Main Colliery, Yorkshire. The experiments were made on the pure coal, *i.e.*, coal as free as possible from pyrites, and on the coal and pyrites mixed. The pyritic coals contained finely divided amorphous pyrites of a grey colour, as well as streaks of crystalline "brasses." Dr. Wheeler's note on these experiments is given in Appendix A, and in his own words, "the results show clearly that, under the " conditions of experiment, the presence of pyrites does not increase the rapidity of " oxidation, but exerts a hindering action, probably acting in the same manner as " other inert material."

(5) *The effect of the absorption of Oxygen by the Coal Substance.*

Having considered pyrites and bacterial action as agents primarily responsible for the self-heating of coal, there remains the oxygenation of the coal substance

itself to be considered, and on some aspects of this question it is possible to arrive at a concensus of opinion on the part of the witnesses interrogated by us, though they were not at one on other aspects.

Dr. Bedson held the view that the coal substance, in those cases where self-heating of coal was in evidence, was readily oxidised (*Q.* 2651), and in this connection referred to some experiments which he carried out on coal from the Bullhurst Seam of North Staffordshire a quarter of a century ago. The oxidation is associated with heat production and "unless means are taken for the dissipation of the heat it will "gradually accumulate and gradually raise the temperature of the combustible body "to the temperature of inflammation. When you have slow combustion beginning "in the way I have indicated, the oxidation will be more and more accelerated by the "heat so developed, and thus become what you would call more ordinarily rapid "combustion or inflammation." In one set of experiments he found that the coal readily ignited at temperatures between 180° and 230° C. He said: "in a small "air-bath I had a quantity of this coal dust spread out, and an arrangement made for "a supply of air playing on the surface. When the coal in one set of experiments "was heated to a temperature of 180° C., or 356° F., I got in some cases ignition and "in other cases it required a temperature of 230° C. Making the experiment on a "much larger scale—not necessarily a very large scale—and working on the same "lines, that is to say, with an asbestos tray in an air-bath upon which the fine coal "dust was spread, and above that a copper-spiral perforated below, and air forced "through so that the coal was constantly under the influence of these jets or sprays "of air playing on it—working then with a larger quantity than in the first, but "with the same coal, I found the temperature of inflammation to be between "144° and 160° C." These experiments were carried out on coal from Ryhope Colliery, in the County of Durham, at which colliery, we believe spontaneous combustion is unknown. Carrying out similar experiments on shale and coal from the Fair Lady Pit at Leycett Colliery, North Staffordshire, Dr. Bedson found that, in one experiment, with the air bath at a temperature of 122° C., in 6 hours the temperature of the shale rose to 151° C., and in another experiment, with the air-bath at 110° C., in 3 hours it rose to 164° C. This shale is notoriously suspect in regard to the occurrence of underground fires in North Staffordshire. (*See* Section III. (1)).

The experiments, as will be seen later when we come to treat of the occurrence of actual fires underground, are of importance as reproducing the conditions which frequently occur in practice, viz., the passage of air—the "breathing," as Dr. Haldane terms it—through crevices in the coal caused by crushing and containing coal dust.

It might be argued that the rise in temperature indicated in Dr. Bedson's experiments was due to the presence of pyrites in an oxidisable form, but on this point he remarked that "I think we have rather dismissed the influence of pyrites. "I think there must be present in that coal substances which are readily oxidised. "Of course, we know so little . . . . about the constitution of the compounds "contained in coals, that it is difficult to put your finger on any particular set as the "source of this oxidation." (*Q.*) "But do you not attach very great importance in "the problem to the presence of pyrites?" (*A.*) "No, I cannot say that I do. I "should look at it from this point of view: that in the first place the proportion of "pyrites is very small compared to the whole of the coal substance, and in the coal "substance I say, the greater proportion of it, or a larger proportion of it, must "consist of easily oxidisable bodies. You have the oxidation of the disposable "hydrogen in the coal leading to this formation of water and the oxidation of some "of the carbon leading to carbon dioxide. In addition to that you have the "formation, I should take it, by the combination with oxygen, of new compounds, "coal-like in appearance certainly, and I suppose we should speak of them as coal, "because they are black and combustible. All these are factors in heat production" (*Q.* 2657).

Subsequent to his work on the coal from the Bullhurst Seam, Dr. Bedson discovered many years ago that pyridine is a solvent of a good part of the coal substance of certain coals, and suggested its use as a solvent for extracting from the coal substances which would oxidise readily on exposure to the air. He was asked: "Then, of course, if by some solvent of that sort one found that the Bullhurst Seam, "for instance, contained a higher percentage of compounds soluble in pyridine or "something else, than, say, Durham coal, that would take us a long way," and replied: "Yes, it should help" (*Q.* 2661).

Dr. Bedson alluded to the unsaturated compounds that are present in coal; he said that "as an example of an unsaturated compound one would take a paraffin " hydro-carbon; marsh gas is the first member of that series. It is what we describe " as a saturated compound. Ethylene or olefiant gas is an unsaturated compound. " The difference between the two is shown by their behaviour to bromine or chlorine. " Bromine has no immediate action upon marsh gas, whereas if you shake up ethylene " gas with bromine the latter is immediately decolourised. It combines at once with " ethylene forming ethylene di-bromide" (*Q.* 2683). Thus, the difference between a paraffin hydro-carbon and an olefine, or between marsh gas and olefiant gas, is that whereas, if marsh gas suffers any chemical change, it is at the expense of the hydrogen it contains, the ethylene gas can add on to itself other elements or compounds by direct addition. The inertness of the saturated compounds gives an explanation of the origin of the term paraffin (*Q.* 2716). The bearing of this from the point of view of the self-heating of coal is that oxygen combines with these unsaturated compounds in the coal to form stable substances and in the process of combination heat is evolved.

Dr. Bedson put forward what we consider is a valuable suggestion as pointing to a method of determining whether a coal is dangerous from the view-point of liability to self-heat. He said: "These compounds, in this behaviour, have their analogues " in the drying oils, which by absorption of oxygen from the air gradually form " dry resinous solids. Like such oils, coal will absorb iodine, and this iodine " absorptive power might be utilised to ascertain the proportion of such substances in " a coal; just as the behaviour of coals towards dilute solutions of potassium per- " manganate may be employed to indicate the proportion of easily oxidisable bodies " in coal. The iodine absorption value in a coal might give information as to whether " coal contains a considerable proportion of these unsaturated compounds or not, just " in the same way as its behaviour with potassium permanganate" (*Q.* 2686).

During the early stages of our inquiry we were anxious to determine whether any catalytic action could be attributed to coal in the same way that the physical absorption of hydrogen by spongy platinum results in the production of heat. But the evidence of Dr. Bedson did not support this as explaining the self-heating of coals. (*See also* Mr. Winmill's view, page 26.) He instanced the action of oxygen on charcoal, but pointed out that some coals liable to spontaneous combustion and shales liable to self-heating are very compact, and added that in the chemical nature of coals themselves there is sufficient to explain the large proportion of oxygen absorbed. He said: "I do not think it is likely to be entirely physical. In the case of coal it will be " both physical and chemical."

Dr. Haldane, who has been interested for many years in the subject of the gases produced in mines, told us that his interest in spontaneous combustion first arose in connection with the effects on men of the gases and heat given off by the action of air on coal, and that he approached the subject from rather a different point of view from that of other chemists who have investigated it. Black damp, which occurs in all mines and consists roughly of from 80 to 90 per cent. nitrogen and the remainder carbonic acid, is, in his opinion, the result of slow combustion, using the term in its scientific sense; that, in the action of the oxygen of the air on coal, the air is deprived of some of its oxygen while the nitrogen remains, the carbonic acid formed being the direct result of the action of the oxygen on substances in the coal (*Q.* 6998–7036). He said: "In no mine in England have I found anything like pure carbon dioxide " or practically anything more than a gas consisting of nitrogen with 20 per " cent. of carbon-dioxide — such a gas as might be simply the residual gas from " a slow oxidation process (*Q.* 7036). Heat is always produced in a process of " oxidation, and this at once affords an explanation of the fact that the return " air of a coal mine is usually above the temperature of the strata, and that the " workings themselves are often warmer. I made a number of observations on this " point at Hamstead Colliery in conjunction with Mr. F. G. Meachem in 1898-9" (*Q.* 7052). In a paper* read before the South Staffordshire and East Worcestershire Institute of Mining Engineers in October 1898, these authors state that at the Hamstead Colliery in South Staffordshire, where the Thick Coal is worked, "from the " pit-bottom, the temperature of the air rises steadily along the main intake airways

* "Observations on the Relation of Underground Temperature and Spontaneous Fires in the Coal to Oxidation and to the causes which favour it," by John S. Haldane, M.D., F.R.S., and F. G. Meachem, M.Inst.M.E. Trans. Inst.M.E., 1898, vol. XVI., page 457.

"at the same time becoming less and less affected by changes in the temperature at "the surface. Following the main north intake airway, the rise is at the rate of 60° "for every 3,000 feet." They showed that "the whole, or nearly the whole of the "heat which is constantly being withdrawn from the workings and roads of the pit "by the air current is derived, not from the natural heat of the undisturbed strata, "but from processes incidental to the working of the pit."

We doubt whether the whole of the black damp found in mines can be accounted for by the oxidation of the substances forming the coal seam. It is probable that coal seams give off carbon dioxide as they do light carburetted hydrogen (marsh gas or methane); for instance, it is a well-known fact that violent outbursts of carbon dioxide (carbonic acid) occur in some coal mines in central France. One would expect to discover the presence of carbon monoxide in mines as a result of the slow or incomplete combustion of the coal, which is in other words oxidation. Dr. Haldane was puzzled to account for its absence. He said: "There is apparently no CO, at least I have "never been able to find any unless there was heating, which puzzles me very much. ". . . . Because, when you take the coal in the laboratory and let oxygen act on "it, you do get a little CO at low temperatures." But he has no doubt that it will be found (*Q.* 7001–2 and 7030).

Dr. Haldane was of the opinion "that ordinary black damp in the return air of "the mine is probably not formed very much from the coal. It contains a lot of "carbonic acid, whereas when coal takes up oxygen it forms almost no carbonic "acid" (*Q.* 13,340). He took the view that the carbonic acid was derived chiefly from oxidation of timber, and that it was due, not to chemical action, but to decomposition of the timber.

Some experiments commenced at the Doncaster Laboratory and completed at Cambridge University by Mr. Lamplough and Miss Hill under the direction of Dr. Haldane, had for their object the determination of the proportion of heat production corresponding to the absorption of oxygen by freshly broken coal. Mr. A. V. Hill (Miss Hill's brother) devised delicate methods at Cambridge for measuring the heat produced by slow oxidation of coal. The mean result was that in the absorption by coal of one cubic centimetre of oxygen sufficient heat was produced to raise the temperature of one cubic centimetre of water 3·3° C. That is only about two-thirds of the heat that would be formed if the oxygen were used in actually burning the coal. Later experiments carried out with fresh coal by Mr. T. F. Winmill gave a heat production about one-third lower, and it seems possible that in the Cambridge experiments, there was an under-estimate of the oxygen absorbed, the coals experimented upon being the same in both cases. The heat production was considerable, but a good deal less than if the oxygen were used in burning the coal to carbon dioxide and water. Some intermediate product seems, therefore, to result from oxidation, but what that intermediate product is Dr. Haldane did not know (*Q.* 7320).

Dr. Haldane found that the absorption of oxygen and nitrogen—for coal absorbs both these gases—by the coal substance, is strictly proportional to the pressure. "It "is a very considerable amount, and you have got to allow for it in all your "experiments. This physical absorption has no significance, or hardly any, as regards "heat. There is hardly any heating when the oxygen goes into physical solution or "absorption, but when it is a chemical combination, of course it has a big heat effect, "so you have to deduct one from the other and look out for it in your experiments" (*Q.* 13,286).

He showed that it is the fresh coal which takes up oxygen; the old coal dust lying about a mine is inert because already oxidised, but the case is quite different in regard to *blocks* of coal. "Coal will still fire after 50 years if you break it up." He stated also that "any sort of coal we have ever examined oxidises sufficiently to produce gob "fires." It is only a question of size and insulation, and we cannot do better than reproduce the witness's view thereon by repeating his own words: "You have a heap "of more or less finely divided coal and an air current through it. The air meets the "coal, and loses a little of its oxygen and produces a little heat. The heat is carried "on and heats up the coal beyond, and more air comes in and it in its turn is heated "up and the heat is carried on. At the place where the air first enters the coal it "probably can never heat up, because the heat is carried off as soon as it is set up; "but further in, the temperature increases and has a cumulative action, so that, "however little heat is formed by oxidation, that heat accumulates and you get a "temperature which will set the whole thing on fire" (*Q.* 13,315).

In the discussion following a paper read by Dr. Haldane before the Institution of Mining Engineers in 1917,* *Professor Bone* stated that "the more recent work of " S. W. Parr and F. W. Kressman in 1910 (University of Illinois Bulletin No. 16) was " specially interesting because of their conclusion that for any given coal there is a " certain 'critical temperature' (between 140° and 160° C. in oxygen, and 200° to 290° " C. in air) at which the oxidation became autogenous (*i.e.*, self-propellant)." "I " think," said Dr. Haldane, "the idea is quite unsound, and I do not agree in the " least with Professor Bone. . . . ." He (Dr. Haldane) thought that "the paper " had made it perfectly clear that there is no known temperature at which the heating " of coal becomes for the first time 'autogenous' or 'self-propellant,' and he was " surprised to find that Professor Bone still clings to the idea that a 'critical' " temperature of this kind exists, otherwise than in relation to the particular " conditions under which some particular observation was made. . . . Professor " Bone seemed to think that you can tell by examining a sample of coal whether it is " capable of producing a fire or not. I should say any kind of coal, at a temperature, " would produce a fire. . . . If you take a small vessel full of coal, a very small " quantity, say a gram or so, it will not become autogenous until it is nearly red hot, " and supposing you have made it already red hot you have only to scatter it about " and it goes out. If you want to put out a bonfire you kick it out. In that case you " have never got to an autogenous temperature" (*Q.* 13,334–6). We have quoted Professor Bone's views as to autogenous oxidation and Dr. Haldane's comments thereon; we are in agreement with Dr. Haldane that the theory of autogenous oxidation as applied to coal at comparatively low temperatures is unsound for the reasons he gives.

On the point that coals contain certain unsaturated compounds and that in this respect they vary greatly as to the amount and character of their readily oxidisable organic constituents, Professor Bone held views similar to those advanced by Professor Bedson (*Q.* 3288.) His views on this subject are so interesting that we quote his evidence at some length. He said: "I think, in the first place, there is no " doubt that coal without pyrites (if we could get coal without pyrites at all. say a " bituminous coal) is capable of absorbing and probably entering into chemical com- " bination with oxygen. I do not think it is a mere occlusion of oxygen that goes " in and which you can get out as oxygen again, and I think it is a compound which " might be well worthy of careful investigation with a view to establishing whether " that oxygen is merely occluded, which I do not think it is, or chemically united " with the coal substance to form an oxygenated coal substance. Now, of course, " coal substances, according to the work which has been done by Wheeler and " Rhead, who have published a very valuable research on the subject, are of " two types, one being the more resinous type, which gives rise on destructive " distillation to hydro-carbons, and which, according to Wheeler and Rhead's " work, is wholly decomposed at temperatures below 600° C. and the other " type may be called a cellulose derivative. With regard to the resinous type, " it is that type of constituent which is extractable by pyridine. That obser- " vation was first made by Professor Bedson. Then with regard to the other type, " which may be called a cellulose derivative, arising as it probably does from " the cellulose of the original wood fibre, it does not decompose until a higher " temperature than 600° C. is reached, and then it gives rise to hydrogen. I should " say that certainly both types of constituents would be capable of absorbing " oxygen at fairly low temperatures. I should be prepared to find that both classes " of constituents would absorb oxygen, but I should rather anticipate that the resinous " constituents would absorb it rather the more energetically of the two. Still, I am " only speaking of what is my general impression. It would be of great interest to " determine, as could be done by properly carried out experiments of a crucial " character, whether that oxygen so absorbed is in the occluded form or has actually " come into a loose chemical combination. I will venture to surmise that it will be " found to have actually entered into a loose chemical combination rather than that it " is present in the merely occluded form. It is the actual combination of the oxygen " in that loose way with the coal substance which gives rise to the initial evolution of " heat, and which serves to raise gradually the temperature of the coal; in such " circumstances, and to a degree dependent upon the conditions of heat conservation, " the temperature will rise until the heat evolution is just balanced by radiation

* "The Spontaneous Firing of Coal," by J. S. Haldane, M.D., F.R.S. Trans. Inst.M.E., Vol. LIII., pp. 194–226.

" losses, when you will get a temperature equilibrium. It seems to me that provided " the air supply is sufficient, there is no doubt this absorption of oxygen increases in " rapidity with rising temperature, and so the process will go on if the heat is " conserved at a sort of compound interest rate ; the activity of the process and the " amount of oxygen which is finally absorbed will depend on the character of the " coal substance, of course. For instance, some of the continental observers, I think, " say it is known that coals contain substances of an unsaturated chemical character " such as combine ordinarily with bromine, and that those substances also absorb " oxygen. One observer proposed an actual test as to whether coal was safe to store. " Professor Fischer, of Gottingen, in some experiments, an account of which was given " in the 'Gas World' for the 13th April 1901, says coals which most rapidly absorb " bromine are precisely those most liable to rapid oxidation and spontaneous ignition, " and as a practical test he recommended shaking a gramme of finely pulverised coal " with 20 cubic centimetres of semi-normal bromine solution for five minutes, when, " if the whole of the bromine has not disappeared (which can be judged by the smell " of the bromine remaining) the coal may be safely stored."

In answer to the question : "What would be those unsaturated compounds?" he replied, "I imagine they are either hydrocarbons or already oxygenated hydro- " carbons. There is another curious feature which Dr. Wheeler has drawn my " attention to, which he says he has observed, and of which I think there is some " corroborative evidence, namely, that the coals which are most liable to spontaneous " oxidation are those which are already fairly well oxygenated, and therefore contain " a fair amount of oxygen. That may seem to be paradoxical at first ; one might be " inclined at first to think that a coal which had not taken up any oxygen at all " would show more readiness to take it up than another which had. This rather " recalls to my mind some of my experiences in the oxidation of hydrocarbons ; for " instance, in the case of ethane, which on oxidation gives rise first of all to ethyl- " alcohol, I found that after the first oxygen had entered—that is, after the first " hydrogen atom is oxidised to OH—the second hydrogen atom was much more " readily oxidised than the first. For instance, alcohol is much more rapidly oxidised " than the hydrocarbon from which it is derived by oxidation. (*Q.*) And so along all " the scale?—(*A.*) Yes, I think the first oxygen atom which goes in, so to speak, " shows the way for the other to follow ; after you first break into the hydrocarbon " molecule and get one hydrogen atom oxidised to hydroxyl, there is a greater " tendency for the remaining ones to be so oxidised. (*Q.*) That is a chemical fact, I " take it?—(*A.*) Yes, in the slow oxidation of hydrocarbons. Now if we have a " similar process to do with in the case of coals, it would explain the observations " which Dr. Wheeler has told me of privately, and which rather bear out some of the " evidence of the experiments which I have read, namely, that it is coals which have " already attained a certain degree of oxidation which are most liable to take up " more. I think that is a very interesting point on which work might be done" (*Q.* 3297–3301).

We asked *Mr. Winmill* to give evidence before us, and he did at some length, on the oxidation of coal, as he had investigated the subject experimentally in considerable detail. Speaking of oxidation of the coal substance he said : "It seems probable " that in this reaction lies the main cause of underground heating" (*Q.* 10,750).

The experimental method practised by him was to confine coal dust in a bottle kept at a constant temperature and to draw air through the dust. From a knowledge of the rate at which the air passed through the dust and an analysis of the air after its passage, it was easy to calculate the rate at which the coal absorbed oxygen. The various parts of the Barnsley seam were tested first at a temperature comparable to that of the strata (81° F.) and afterwards at higher temperatures (*Q.* 10,750–10,759). The net results may be summarised as follows :—

(1) As the temperature rises the coal absorbs oxygen faster and a larger total quantity of oxygen is absorbed.

(2) It was found that the various coals taken from the seam at one place differ little in their power of absorbing oxygen when in the condition of fine dust.

(3) The shale and the "mother-of-coal" are, as compared with the coal proper, much less powerful absorbents.

(4) The influence of temperature on the rate of absorption of oxygen and the quantity absorbed is very marked.

(5) There is comparatively a great absorption of oxygen initially which falls off rapidly as time goes on (which is just the reverse of what would be

expected were the action bacterial). Thus, fresh coal shows a relatively larger absorption of oxygen which falls rapidly during the first 36 hours, after which the rate falls much more slowly, the "curve" then approximating to a straight line.

(6) "2·1 calories of heat were evolved for every cubic centimetre of oxygen "absorbed at ordinary temperatures, which means that if 1 gramme of "coal absorbs 1 cubic centimetre of oxygen, its temperature will rise "about 7° C., or, put in other units, a ton of coal absorbing 1 cubic foot "of oxygen will rise about 3° F. in temperature."

(7) Assuming that no heat were lost during the oxidation, either by conduction, radiation, or evaporation, Mr. Winmill calculated that the Barnsley Bed coal would fire in about 55 hours, a condition which he agreed, however, would not occur in practice as a considerable quantity of heat would be lost by evaporation of water in the coal substance. But allowing for this, he calculated that the coal would fire in a *minimum* of about 8 days.

(8) During the initial part of the oxidation very little carbon dioxide is produced, and at no time during the experiment was an amount obtained comparable to that produced in the pit. The absence of carbon dioxide, as was proved by experiment, is not explained by its absorption by the coal. (Though carbon dioxide is absorbable by the coal experimented upon to a considerable extent, it being about seven times as soluble in coal as in water, the quantity absorbed decreases very rapidly with the decrease in the percentage of carbon dioxide in the atmosphere.) The ratio of oxygen deficiency to the carbon dioxide produced in coal which has been standing about three months is the same, however, as that found in the pit (*Q.* 10,759).

It was the production of carbon dioxide which troubled Dr. Haldane, but the experiments conducted under his supervision at a later date, the results of which were given in evidence before us by Mr. Winmill, cleared up the difficulty. It would appear that the production of carbon dioxide from coal falls steadily until the ratio of oxygen deficiency to carbon dioxide produced reaches that which one finds in the pit. If all the oxygen disappearing formed carbon dioxide, the ratio would of course be unity, and in some cases this figure is nearly reached, but in the Doncaster pits Mr. Winmill determined it at about 4.

As exemplifying the effect of the absorption of oxygen by coal, Mr. Winmill gave as an illustration the fact that the coal at Bentley Colliery (near Doncaster), "in the "absence of any gob fires, was absorbing as much oxygen as a furnace burning half "a ton of coal per hour and producing as much heat as a furnace burning about half "that quantity. The heat and combustion are distributed over a very wide area "indeed, but the effect is as real as if it were concentrated in a furnace."

Mr. Winmill strongly held the view that the oxidation of coal is entirely a chemical and not a physical process. He would not agree that there is any catalytic action whatever (*Q.* 10,773).

He agreed with Dr. Wheeler's view, viz., that since coal is a very complex substance, there is every reason for supposing that a considerable number of the substances constituting the coal take part in the reaction which results in heating. But he differed from Dr. Wheeler and Professor Bone in the belief that coals of high oxygen content are by virtue of that fact more liable to spontaneous combustion than coals of low oxygen content; that is to say, that the absorption of oxygen is greater in the case of coals of high oxygen content than in the case of coals of low oxygen content, but he was not able to satisfy us with any explanation why this should not be so (*Q.* 10,978–10,986).

Dr. Wheeler informed us that he had "started out with the assumption that it "had been practically proved now that self-heating of coal is not due necessarily to "the presence of large quantities of pyrites in the coal, but to an actual combination "of oxygen with the coal substance" (*Q.* 2404), in which assumption he was in agreement with Threlfall, Richters, and Fayol. Generally speaking, this may be taken to reflect the state of scientific opinion at the outset of our inquiry, though many practical mining engineers still held the view that the chief factor was the disintegration by the action of moisture on iron pyrites contained in the coal.

Dr. Wheeler has devoted much time to the work of investigating the underlying causes of spontaneous combustion, and the valuable evidence which he gave to us on two occasions may be epitomised as follows :—

1. From the chemical standpoint alone, the higher the percentage of oxygen contained in a coal the greater the liability to spontaneous combustion. All coals of high oxygen content should be regarded as suspect (*Q.* 12993–6).
2. A high percentage of volatile matter does not necessarily render a coal more liable to self-heating.
3. The percentage of moisture contained in a coal has but little effect in respect of self-heating. He would not like to say that it had no effect.
4. Regarding the coal *en masse*, the reaction responsible for the self-heating of coal is mainly one of attachment of oxygen to molecules of high carbon content. Subsidiary to this reaction, but playing an important part in determining the actual spontaneous ignition of coal, is a chemical interaction between the oxygen thus loosely held by the carbon-like molecules, and other atoms in those molecules, or other portions of the coal conglomerate (*Q.* 12,989).
5. The chemical composition of coal is not by any means the only factor to be taken into consideration when attempting to judge whether spontaneous combustion will occur in practice. Its liability to crush and form fine dust is of high importance in this respect. It is axiomatic that the more finely divided the coal the greater the surface area exposed and consequently the more rapid the oxidation (*Q.* 13,009).
6. Determination of the relative friabilities of thirty coals disclosed the fact that coals with low oxygen content have, as a general rule, high friability and *vice versâ* (*Q.* 13,010).
7. He was doubtful as to whether bacteriological action has any bearing on the self-heating of coal (*Q.* 13,048).

From the practical standpoint the most important matter disclosed by Dr. Wheeler's evidence was that a high percentage of oxygen in combination with other constituent bodies renders a coal more liable to self-heating.

The ultimate constituents of the pure coal substance—and by coal substance we mean the coal freed from the ash content—are carbon, hydrogen, oxygen, nitrogen and sulphur, and the percentage of oxygen varies between wide limits, say, from 1 per cent. by weight in anthracite coals up to 17 to 20 per cent. by weight in some bituminous coals. Dr. Wheeler determined, after experimenting on 50 different coals, that with very few exceptions the higher the percentage of oxygen in a coal, the lower is the temperature at which self-ignition takes place. This was in respect of coal apart from any adventitious bodies such as pyrites (*Q.* 2419). He regarded as a high oxygen content 10 to 15 per cent. When the oxygen content was 6 per cent. or less he regarded the coal as "non-suspect" from the chemical point of view of liability to self-heat (*Q.* 13,001 and 13,003).

The following table shows the results in respect of oxygen contents and relative temperature of self-heating in the case of 32 experiments conducted by Dr. Wheeler, but it should be borne in mind that there are factors other than chemical composition that affect the liability of a coal to self heat and in some of the coals mentioned in the table, these other factors would seem to be exaggerated :—

TABLE I.

Lab. No.	Seam and Colliery.	Oxygen Content.	Relative Temperature of Self-Heating.
		Per cent.	°C.
213	Mossfield, Sneyd Colliery, Burslem	11·13	165
218	Ell, Blantyre Colliery, Blantyre	11·12	167
210	Burnwood, Sneyd Colliery, Burslem	11·09	165
248	Lowery, Forest of Dean	10·61	177
251	Coleford Highdelf, Forest of Dean	10·51	176
234	Main, Florence Colliery, Staffs.	10·26	176
246	Churchway Highdelf, Forest of Dean	9·95	179
208	Hard Mine, Sneyd Colliery, Burslem	9·94	179
207	Rough Seven Foot, Sneyd Colliery, Burslem	9·93	177
211	Two Foot, Sneyd Colliery, Burslem	9·54	178
235	Moss, Florence Colliery, Staffs.	9·18	178
201	Wigan Six Foot, Moss Hall Colliery, Wigan	8·78	187
231	Barnsley Thick, Denaby and Cadeby Main Collieries, Rotherham	8·78	183

TABLE I.—*continued.*

Lab. No.	Seam and Colliery.	Oxygen Content. Per cent.	Relative Temperature of Self-Heating. °C.
206	Holly Lane, Sneyd Colliery, Burslem	8·70	186
241	Hulton Two Foot, Hulton Colliery, Lancs.	8·60	183
225	Banbury Eight Foot, Birchenwood Colliery, Stoke	8·55	185
247	Rocky, Forest of Dean	8·30	182
240	Arley, Hulton Colliery, Lancs.	8·06	180
216	Maudlin, Washington Colliery, Durham	8·02	183
224	Banbury Seven Foot, Birchenwood Colliery, Stoke	7·63	192
226	Bullhurst, Birchenwood Colliery, Stoke	7·44	188
200	Arley Mine, Arley Springs Colliery, Hindley Green	7·32	185
205	Main Band, Whitehaven Colliery, Whitehaven	7·05	192
239	Hutton, Murton Colliery, Sunderland	6·73	195
215	Hutton, Shotton Colliery, Durham	6·64	206
230	Banbury Seven Foot, Burley Pit, Apedale Colliery, Staffs.	6·38	200
214	Silkstone, Barrow Collieries, Barnsley	5·64	210
203	Carnock, Alloa Collieries, Alloa	5·41	200
217	Lower Black Vein, Celynen Colliery, Newport	5·12	217
232	Busty, West Stanley Colliery, Durham	4·95	195
227	Beaumont, Walker Colliery, Walker-on-Tyne	4·71	220
228	Busty, Beamish Mary Pit, Durham	3·93	200

Coal is really a highly complex conglomerate of the degradation products of cellulose substance, the main ingredients being of two types, viz., "humic substance" and "resinous substances." The reason for the liability of coals of high oxygen content to self-heat is thus explained by Wheeler: "The former, derived mainly from "celluloses, probably contains compounds whose molecules possess the structures "that exist also in the carbon molecule, and have the power of loosely attaching "oxygen. The latter give to coal its ready inflammability, being very easily oxidised "and having a low ignition temperature. It seems a natural conclusion to draw "from this knowledge of the characteristics of the components of the coal substance "that the exothermic reaction observed when coal is heated in the absence of air "between 150° and 250° arises from interaction between the oxygenated compounds "in the coal conglomerate and the resinous constituents. The heat thus evolved "would increase the rate of combustion of the coal as a whole by atmospheric "oxygen, so that a coal containing a high proportion of oxygenated compounds would, "as indeed is found to be the case, be more liable to self-heat than one containing a "low proportion." Or the process can be stated in another way: after the heating of the coal has proceeded to a certain extent by atmospheric oxidation, a temperature is reached at which there is an interaction between the oxygen compounds in the coal and the more inflammable parts of the coal substance; that is to say, there is actual self-heating of the coal, the oxygen compounds in the coal feeding, so to speak, upon the more inflammable portion of the coal substance. For instance, it might be possible for spontaneous ignition of coal to take place due to the interaction between one part of the coal substance and another part after oxidation had proceeded to a certain point through the agency of the oxygen of the air.

A brief account of the methods by which Dr. Wheeler carried out his experiments is given in Appendix B.

That coal may be regarded as a conglomerate of at least two different bodies is shown by the investigations of Mr. Lomax and Dr. Marie Stopes, and of Dr. Wheeler and Mr. Burgess (*see* papers by Wheeler and Burgess in Journal of Chemical Society), the one type derived from the resins and gums originally present in the plants forming the coal, the second type from the degradation products of the celluloses or woody fibre of the coal plants. The former are readily decomposable by heat, yielding the paraffin hydrocarbons as their main gaseous product; the latter type require a higher temperature to decompose freely, the gases then evolved being chiefly hydrogen and the oxides of carbon. These two types may be termed respectively the resinous and the humic substances. The characteristics of the two substances are epitomised by Dr. Wheeler respectively as:—

Resinous substance: (*a*) Melting at 100° C.
(*b*) Yield half their weight of "volatile matter."
(*c*) Affect a sensitised plate strongly.

Humic substance: (*a*) Infusible.
(*b*) Yield but little "volatile matter" on heating; but what there is consists mainly of phenols.
(*c*) Do not affect a sensitised plate in the dark.

Dr. Wheeler also inquired into the relative friability of different coals, for, as has been shown, next to the chemical composition the friability of a coal is the most important point respecting its liability to self-heat—indeed, the problem is frequently a physico-chemical one. In a number of experiments carried out at the Home Office Experimental Station at Eskmeals, his method of testing was to treat a sample of each coal (of given weight and in the form of nuts of the same average size in each case) in a ball mill running at a standard speed for a standard length of time, and then to judge the relative friabilities from the percentage of dust formed which would pass through a 200-mesh sieve. The results were as shown in the following table :—

TABLE II.

Lab. No.	Seam and Colliery.	"Relative Friability."
221	Valleyfield Dunfermline Splint, Fife Coal Co.	54
204	Seven Foot, Albion Colliery, Pontypridd	46
222	Valleyfield Five Foot, Fife Coal Company	44·5
203	Carnock, Alloa Coal Company, Alloa	44
228	Busty, Beamish Mary Pit, Durham	40
214	Silkstone, Barrow Collieries, Barnsley	37·5
216	Maudlin, Washington Colliery, Durham	36
200	Arley Mine, Arley Springs Colliery, Hindley Green	35·5
239	Hutton, Murton Colliery, Sunderland	34·5
242	Bullhurst, Silverdale Colliery, Staffs.	34·5
215	Hutton, Shotton Colliery, Durham	32
241	Hulton Two Foot, Hulton Colliery, Lancs.	32
217	Lower Black Vein, Celynen Colliery, Newport	30·5
233	Yard, Florence Colliery, Staffs.	30
234	Main, Florence Colliery, Staffs.	29
238	Beeston, Middleton Colliery, Yorks.	28
211	Two Foot, Sneyd Colliery, Burslem	28
235	Moss, Florence Colliery, Staffs.	27·5
240	Arley, Hulton Colliery, Lancs.	27·5
226	Bullhurst, Birchenwood Colliery, Stoke	27
201	Wigan Six Foot, Moss Hall Colliery, Wigan	27
225	Banbury Eight Foot, Birchenwood Colliery, Stoke	25·5
229	Cockshead, Chatterley-Whitfield Colliery, Staffs.	25·5
205	Main Band, Whitehaven Colliery, Whitehaven	24·5
212	Bowling Alley, Sneyd Collieries, Burslem	24
231	Barnsley Thick, Denaby and Cadeby Main Collieries, Rotherham	23·5
218	Ell, Blantyre Colliery, Blantyre	21·5
219	Main, Blantyre Colliery, Blantyre	21·5
220	Splint, Blantyre Colliery, Blantyre	19
206	Holly Lane, Sneyd Colliery, Burslem	15·5
207	Rough Seven Foot, Sneyd Colliery, Burslem	14·5

Dr. Wheeler found that these coals could be grouped into three classes, viz., low, medium, and high friability. As has been previously stated, those with high friability had generally low oxygen content and *vice versâ*, showing that a tendency towards self-ignition due to high oxygen content is counterbalanced by a resistance to grinding and the formation of small coal due to low friability. This scientific fact has a far-reaching practical bearing, for if crushing by the superincumbent strata can be avoided in the case of coals chemically liable to self-heating, fires can be avoided in working such coals, a point to which we shall return when considering the means which should be taken to prevent the occurrence of underground fires. (*See* page 107—Paragraph I. of Conclusions and Recommendations.)

(6) *Conclusions arrived at by the Committee as to the Scientific Explanation of the Self-heating of Coal.*

Having carefully weighed all the evidence before us and epitomising what we have already stated in the body of this Report, we put forward the following main conclusions as the opinions we have arrived at respecting the self-heating of coal, viz. :—

(1) That the self-heating of coal is not in any way due to the presence of bacteria and that bacterial action, even if it occurs in coal, does not account for even the initial stages of self-heating.

(2) That some small amount of heat may be developed by the oxidation of pyrites in coal when it occurs as an amorphous form of marcasite; but that, as pyrites is present in coal in such small proportion as compared with the coal substance proper—which is a bad conductor of heat—the effect of this heat is negligible. The chief part played by pyrites when present in an unstable form is that of a disintegrator of the coal, so rendering the latter more permeable by air and exposing a greater area of coal substance to oxidation.

(3) That the presence of moisture in coal has an accelerating effect on its oxidation, and consequently that coals high in hygroscopic moisture absorb oxygen more readily than those of low moisture content.

(4) That the self-heating of coal is mainly due to the absorption of oxygen by the coal resulting in the generation of heat.

(5) Though coal absorbs both oxygen and nitrogen in a physical sense as well as in a chemical sense, the absorption in so far as heating effects are concerned is a chemical and not a physical process; that the chemical process is mainly one of attachment of oxygen to molecules of high carbon content, but that subsidiary to this, and playing an important part in determining the actual spontaneous ignition of coal, is a chemical interaction between the oxygen thus loosely held by the carbon-like molecules and other atoms in these molecules or other portions of the coal conglomerate.

(6) That, from the chemical standpoint *alone*, the higher the percentage of oxygen contained in a coal the greater, it would seem, the liability to spontaneous combustion.

(7) That the texture of the coal is a matter of great importance, seeing that the more permeable is a coal, other things being equal, the greater are the effects of oxidation, inasmuch as a greater surface is exposed to the action of the air as compared with a coal of closer texture.

(8) That as the temperature rises the rate of absorption of oxygen increases.

SECTION III.

THE PRACTICAL ASPECT OF THE SUBJECT AS APPLIED TO COAL MINES.

The fact that spontaneous combustion of coal in mines is not general throughout the coalfields of Great Britain, being much more common in some than in others, and the further fact that conditions vary locally where underground fires are of frequent occurrence, have led us to consider the subject by coalfields or parts of coalfields.

In the Durham portion of the Great Northern coalfield, for instance, we can find only one authenticated instance of spontaneous combustion below ground, and in the Northumbrian portion of that field but three cases. So far as we are aware, no case is known to have occurred in the anthracite mines of South Wales, and spontaneous combustion is rare in the mines of Scotland, except in the district of Fifeshire.

We propose dealing, therefore, in the following sequence with the districts in which the occurrence of spontaneous ignition of coal is common, viz. :—

(1) North Staffordshire.
(2) South Staffordshire.
(3) Warwickshire.
(4) Yorkshire.
(5) Lancashire.
(6) Forest of Dean (Gloucestershire).
(7) Fifeshire.

During the course of our inquiry we heard evidence on the practical aspect of the subject from various classes of officials and workmen from representative collieries in the districts named. We have endeavoured to co-ordinate that evidence in such a manner as to indicate the opinions held by practical men as to the occurrence of spontaneous combustion, the conditions conducive to such outbreaks, and the means which are practised or should be practised with a view to preventing their occurrence or combating them when they do occur.

For purposes of easy comparison, we deal with each district separately under the following sub-headings, viz. :—

(A) Geological conditions.

(B) Mining conditions.

(C) Preventive measures :—

(i) The methods in operation for preventing gob fires.

(ii) The methods in operation for dealing with gob fires when they occur.

(A) It has for long been realised that geological conditions play an important part in the study of the subject under review. For example, it is undoubtedly a fact that roof conditions, inclination, thickness of seams, depth of seams from the surface, presence of faults and other geological disturbances have an influence in one way or another on the occurrence of spontaneous combustion of coal below ground.

(B) Methods of working are of vital importance. Some of the points which must be considered as the resultant of the method of working are :—coal left in wastes ; crushing of pillars ; leakage of air across gateways, through packs or wastes ; and timber left in wastes. The "waste" is another matter which must be considered in the light of the evidence of the witnesses. In certain localities there is a time-honoured custom of "drowning" the waste with gas, with a view to preventing the occurrence of gob-fires. During the examination of witnesses we laid stress on the possibility of timber left in the waste being conducive to the outbreak of fire.

The subject of hydraulic stowage of wastes occupied a considerable portion of our time, and we were at pains to elicit information thereon, not only from the officials of the collieries, but also from *Mr. K. Seidl*, a German mining engineer, who had devoted much attention to the problem, and whom, by permission of *Mr. Williger* and of the German Government, we were enabled to employ for the purpose of examining certain

British coal mines from the point of view of the applicability thereto of the system of hydraulic stowage in use, with such satisfactory results, in the Westphalian and Silesian coal mines.

1. NORTH STAFFORDSHIRE.

Introductory.

The coalfield of North Staffordshire has for many years been notorious for the prevalence of underground fires due to the spontaneous combustion of the coal. Several seams are subject to self-heating, and these include the *Great Row, Cannel Row, Winghay, Rowhurst or Ash, Yard, Ragman, Rough Seven Feet, Hams, Ten Feet, Banbury, Cockshead,* and *Bullhurst* seams. Of these, the last two named are the most liable to self-heating and are those which were dealt with at greatest length by witnesses. All the seams vary considerably in their physical properties, in their value from an economic point of view, and in the local conditions under which they are worked as regards thickness, inclination, and nature of roof and floor. In few other districts do these conditions vary to such an extent in so restricted an area, and their combination tends to present difficulties which are reflected in the methods adopted in working the coal.

The following sections are taken from the evidence and from plans produced in evidence, and are illustrative of the above remarks.

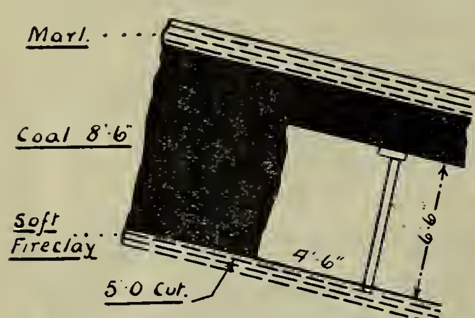


Fig. 1. Great Row Seam (*Q.* 1172).

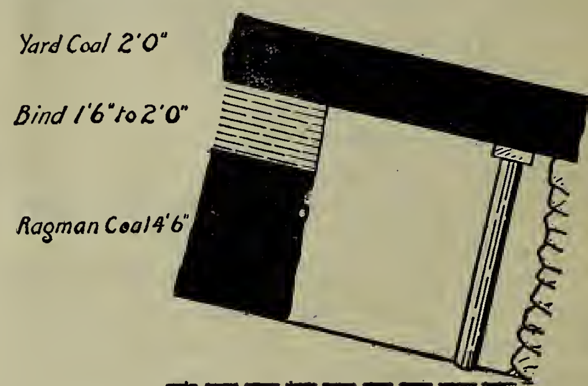


Fig. 2. Yard and Ragman Seam (*Q.* 1172).

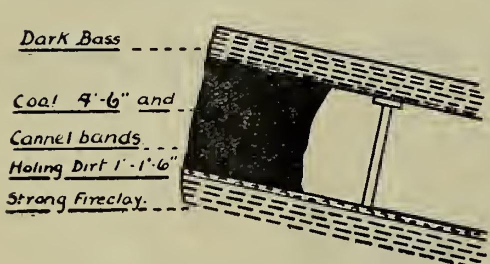


Fig. 3 Cannel Row Seam.

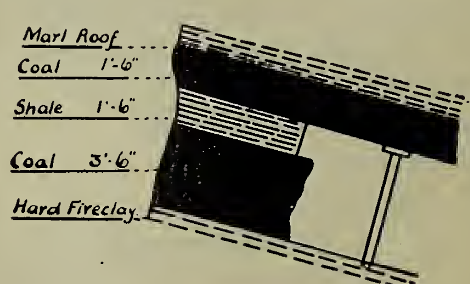


Fig. 4. Winghay or Knowles Seam.

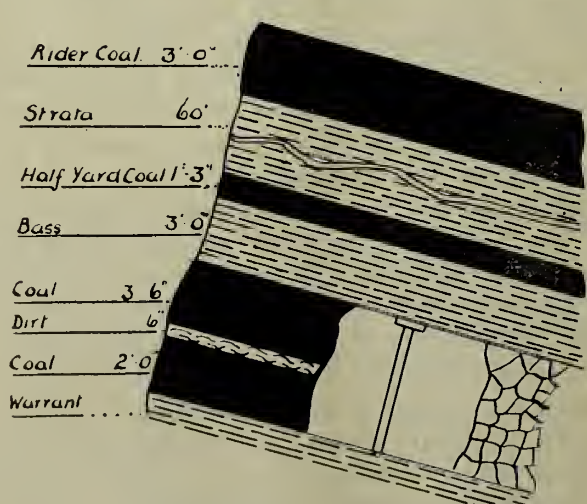


Fig. 5. Rowhurst Seam (*Q.* 1172).

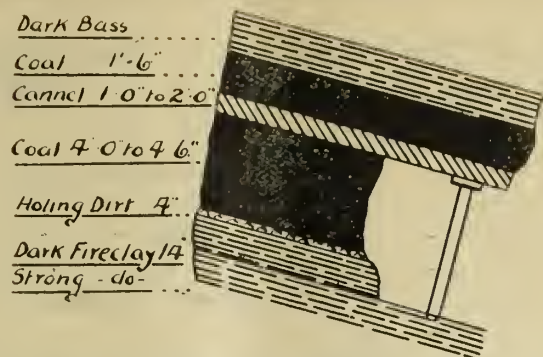


FIG. 6. CANNEL ROW SEAM (Q. 1172).

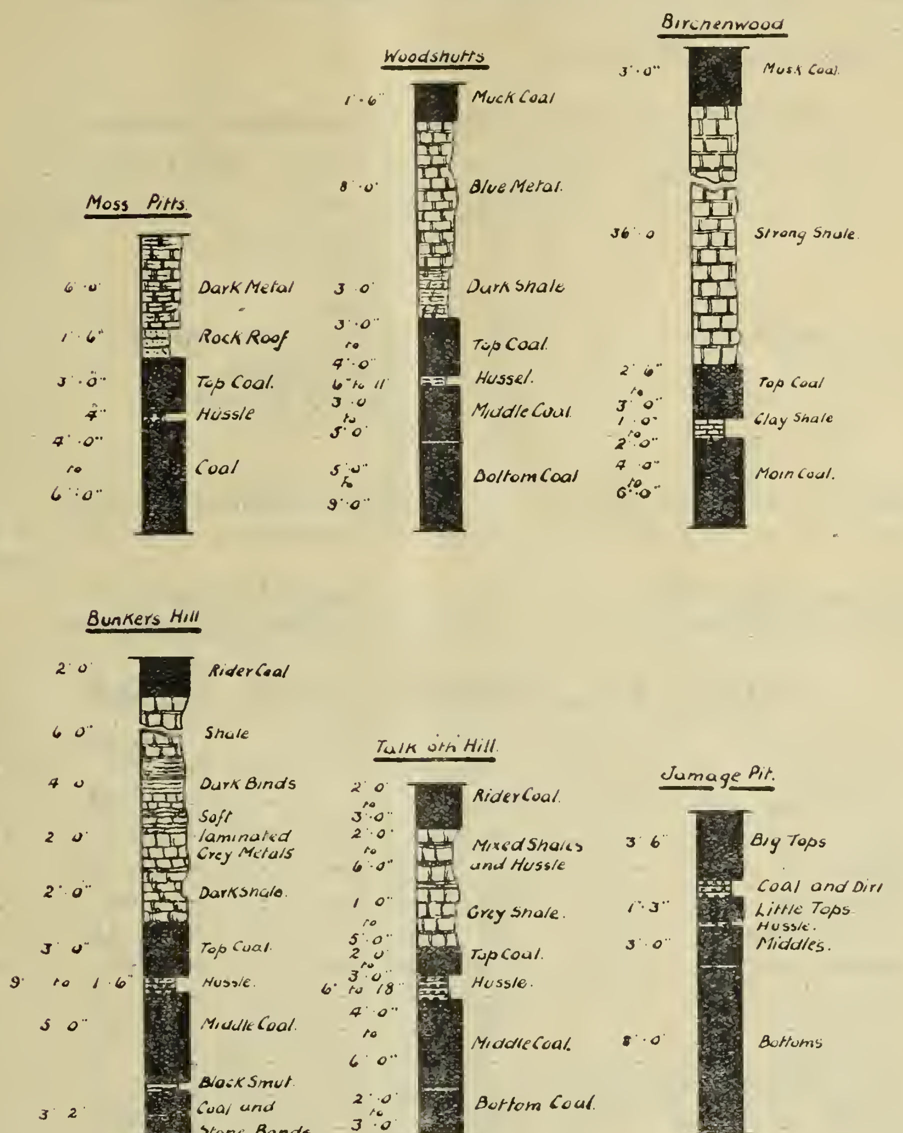
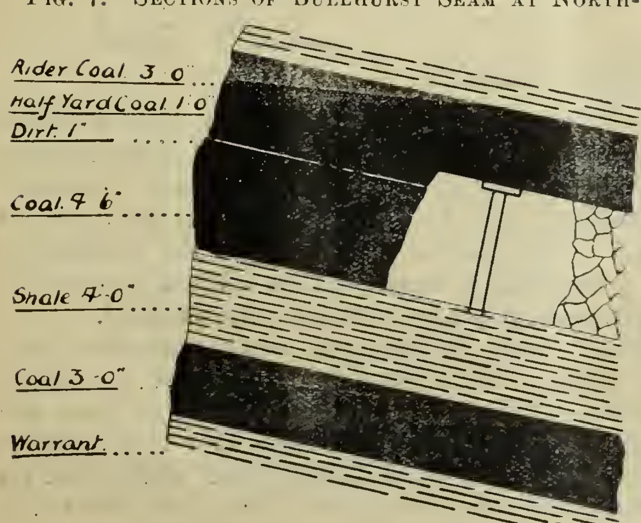


FIG. 7. SECTIONS OF BULLHURST SEAM AT NORTH-WEST STAFFORDSHIRE COLLIERIES (Q. 423).



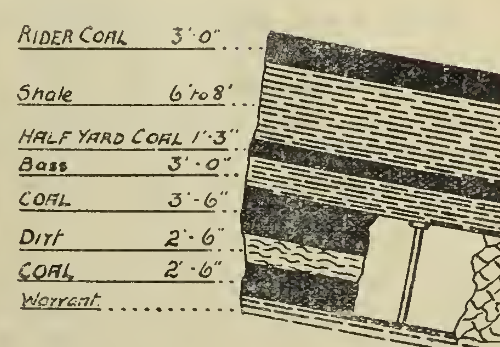


FIG. 8. ROWHURST SEAM (Q. 1172).

FIG. 9. ROWHURST SEAM (Q. 1172).

STONEY EIGHT FEET SEAM, BROWN LEES COLLIERY (Q. 1445).

	Ft.	ins.
Clod roof.		
TOP COAL	3	0
Dirt Band	0	3
BOTTOM COAL	5	0
Soft Warrant floor	—	
Total thickness	8	3

A friable coal lying at an angle of 75 degrees.
Depth from surface, 220 yards.

NORTON COLLIERY (Q. 1429) COCKSHEAD COAL.

	Ft.	ins.
Roof—Shale	16	0
COAL	8	0
Floor—Warrant	5	0

Inclination 14 degrees.

SEVEN FEET BANBURY SEAM. (Q. 1468) (1).

	Ft.	ins.
Rock roof.		
COAL	8	6
BILLY COAL (inferior)	0	8
Fireclay Warrant	—	
Total thickness removed in working	9	2

Depth from surface 430 yards.
Inclination 38 degrees.

BIRCHENWOOD COLLIERY. (Q. 1485) (2).

	Ft. ins.	Ft. ins.
Rock roof.		
Bastard rock	2 0	—
Clod	5 0	—
COAL	—	6 8
BILLY COAL (inferior)	—	0 6
Soft Warrant	0 6	—
Strong Warrant	3 0	—
Rock	—	—
Total thickness removed in working	7 ft. 8 ins.	

Depth 400 yards.
Inclination 27 degrees.

BULLHURST COAL, SILVERDALE, NORTH STAFFORDSHIRE.

	Ft. ins.	Ft. ins.
Dark Grey Bass	—	6 0
TOP COAL	2 9	—
Dirt	—	0 ½
JACKS	0 8½	—
Hussle	—	0 ½
MIDDLE COAL	1 11	—
Hussle	—	0 1
WALL COAL	2 4	—
Parting	—	—
BILLY COAL	0 8	—
Strong Fireclay Warrant	—	4 3
Grey Rock	—	—
	8 4½	10 5

(A) *Geological Conditions.*

Some of the abnormal conditions ruling in this district have been caused by the presence of an anticline dividing the coalfield. On the eastern side of this anticline the measures fall away with a comparatively easy gradient, while on the west they first assume a position approaching the vertical and then flatten out until they are cut off by the Great Western Boundary Fault. The ground to the west of the anticline is very much faulted and contorted, and occupying a narrow area immediately to the west is the "Rearer" coalfield where the seams at places overhang the vertical.

To the west also the seams are thicker, more friable, and more associated with bands of inferior coal and carbonaceous shale. There are fine flakes and threads of pyrites in the coal itself, and disseminated throughout the whole mass of coal are fine microscopic particles of pyrites (Q. 362). It is of interest to note also that some of these seams are of a highly bituminous character and that they coke well, while on the eastern side of the anticline they are for the most part less bituminous and

non-coking (*Q.* 340). Although spontaneous combustion is much more prevalent in those seams possessing highly bituminous characteristics, *Mr. A. M. Henshaw*, Director and General Manager, Talk-o'-the-Hill Colliery, Stoke-on-Trent, did not consider that the bituminous property of coal had anything to do with spontaneous combustion either in North Staffordshire or elsewhere (*Q.* 381).

Questioned as to whether importance could be attached to the anticlinal seams cropping out in the one case and not in the other, Mr. Henshaw replied: "I do not "think that has any bearing on the proneness or otherwise to gob-fire. It has as to "its bituminous character or otherwise. The strange thing is that, anticlinal or no, "in the same seam of coal gob-fires occur at one colliery under almost every "conceivable condition, and never occur at the next colliery although the conditions "are indentical" (*Q.* 393). "In the colliery" (however) "where no gob-fires took "place, the coal I think was better and more of it got out. In the colliery where "gob-fires took place the seam in many parts was inferior. A great deal of coal was "lost in working" (*Q.* 399).

At Mossfield Colliery, where the ground is faulty, an area is found where oil exudes from the roof, emanating from a bed of shale some 18 ins. in thickness situated 12 yards above the Cockshead Coal. This oily shale is a "great source of danger and "risk; the falls in the goaf bring it down and it is liable to spontaneous combustion" (*Q.* 108).

We interrogated all the witnesses with regard to the bearing on the subject of roof and floor conditions, and with regard to the various beds splitting up the coal seams. We found that the stratum immediately overlying the Bullhurst seam was generally suspected of being a contributory cause at least of spontaneous combustion. Mr. Henshaw described this roof as being "a soft broken shale that has taken the "thrust and crush and has been reduced to a crumbled slicken-sided state, so that nips "will break into innumerable smaller pieces each presenting a black polished surface "which is locally called hussle (*Q.* 427). The 'hussle' itself is a very fine and highly "carbonaceous shale."

Mr. Caleb Johnson, Manager of Mossfield Colliery, described the Cockshead hussle as being a dry carbonaceous shale which fritters to dust, but which is not in itself liable to spontaneous combustion. On one occasion only was it observed to heat, but when the hussle falls into the waste it is liable to fire when mixed with slack (*Q.* 108). Mr. Henshaw said of it: "the hussle may under favourable conditions take fire "spontaneously, but as a rule it does not fire" (*Q.* 428).

Mr. A. Daniels, Manager of the Bignall Hill Colliery, after describing the Bullhurst seam, was asked if the hussle by itself would cause a fire. He replied in the negative (*Q.* 2039). *Mr. D. Bailey*, a collier having experience in North Staffordshire, was positive that the hussle was a contributory cause and said: "the hussle and what I "should call the inferior coal, the jacks, containing a certain amount of stone or "brasses, form a blanket over the top of the hussle, and, to my mind, the strata lift "when you are working, and that sends some of this dust out, and the friction sets up "the heat in the hussle" (*Q.* 5830).

Apart from the liability of the hussle to self-heating, this and other roofs have a direct bearing on the subject. If the roof is weak or liable to fall easily, the tendency is to leave a certain portion of the coal for its support. The coal left ultimately falls with the breaking roof into the waste, and we think it is probably for this reason that the hussle composing the roof has come to be considered as the cause of fires, while, in all probability the fires actually originate in the crushed coal. Again, it is customary in some cases to remove a gob-fire by digging it out, and this cannot be done if the roof is tender (*Q.* 1217). Further, it was the experience of witnesses that coal seams with a good roof were less liable to spontaneous combustion. As for the floor, it was stated that a coal lying on a hard rock would ignite much more readily than another of similar characteristics having a floor composed of softer material (*Q.* 408), probably due to the fact that in the former case the coal would be more readily crushed. On the other hand, with a soft floor there is less likelihood of all the small coal and slack being cleaned up, especially if water is present.

Nature of the Coal.—It is clear from the evidence that in North Staffordshire it is generally held that a soft friable coal is much more liable to spontaneous combustion than a hard compact coal. Regarding the quality of coal, it is obvious that an inferior seam is more conducive to fires, inasmuch as a greater proportion is, for economic reasons, left underground (*Q.* 408).

As to the bearing on the subject of the thickness of coal seams, witnesses were unanimously of the opinion that gob-fires were unknown in the thin seams of North Staffordshire. A similar fact has been observed in other districts, and is in accordance with the findings of the Silesian Commission on underground fires (*see* page 11). Thus *Mr. Henshaw* said: "I do not know of any fire in a Bullhurst seam less than "7 feet thick. I think it is entirely due to the fact that in working a thin seam of "coal, from 90 to 95, or even 99 per cent., of the coal is got out. In working a "thick seam of coal there is naturally a much greater loss" (*Q.* 1057). *Mr. J. R. L. Allott*, Agent and Mining Engineer at Birchenwood Colliery, did not know of any gob-fires that had occurred in seams where the coal was only 4 feet thick (*Q.* 1733), and Mr. Daniels gave expression to a similar view (*Q.* 2103). We do not think, however, that this is the sole reason nor indeed the most important, as we show later.

Where the inclination of seams of coal varies considerably, it follows as a corollary that the workings will be more irregular than where the gradients permit of the adoption of a definite plan. The amount of inclination is not a serious matter except in thick seams where a high degree of inclination increases the amount of slipping and caverning. Thus Mr. Henshaw said: "The steeper the gradient the "more caverning there must be" (*Q.* 499), and "I do not see any practical means of "avoiding the caverns, and after they are formed I do not see what can be done ". . . . but I say that in a seam like the Bullhurst, where the thickness varies "from 6 or 8 feet up to 20 feet quite suddenly, when you come to a thick pocket of "coal like that, it is advisable in the interests of safety to get that coal out— "notwithstanding a cavern will be formed." In this connection Mr. Allott described one heating thus: "At the site the measures turn and the coal was of a friable nature "lying at an angle of 75 degrees with a clod roof and a soft warrant floor" (*Q.* 1445). At another place, "the measures turned round at right angles . . . . and it was "very highly inclined, the coal was more friable and very sooty. We think it was "due to pressure at the curvature of the measures, and the dirt bands with the "friction and pressure set up the heating" (*Q.* 1451). *Mr. Daniels*, however, said in speaking of his experience in the Bullhurst seam at the Bignall Hill Colliery, that so far there had been no fires in the highly inclined part of the seam, but invariably in the flattest part. He said, further, that the seam usually thickened out in the flat and was more uniform where highly inclined (*Q.* 2028–9).

The depth of seams from the surface has a bearing on the subject for several reasons. Mr. Allott declared that gob-fires are more likely to occur in deep mines than in shallow mines, owing to the greater crush and the increased ventilating pressures that are necessary to ensure adequate ventilation. He said further that in the deep mines the roads are more difficult to maintain (*Q.* 1721–2–3).

The presence of faults affects the method of working and causes the system adopted to be irregular, thereby increasing the dangers of spontaneous combustion, in that the faces are irregular, which conduces to crushing of projecting masses of coal and penetration of air. Faults are usually accompanied by weakening of the adjacent roof strata, and for the sake of safety in such cases, part of the coal is left unworked; this becomes crushed and falls into the waste. Water is frequently found when faults are pierced, and, in many mines, especially in those seams where the floor is fireclay, this again results in portions of the coal being left. Falls are of frequent occurrence in the neighbourhood of faults and in many cases the coal is rendered inferior and of little economic value. In North Staffordshire many instances have been noted of gob-fires being at least partly due to the influence of faults. Thus Mr. Henshaw said: "It is at the same time to be noted that on the west, where a "gob-fire seam is less faulted, is harder, thinner, and has a good roof, fires are rare "or unknown" (*Q.* 376). Mr. Allott, describing the occurrence of one fire in the Bullhurst seam, said: "The coal seam at this point slipped away and was loaded "out. Then a roof fall came, the whole pillar slipped out between two faults" (*Q.* 1455). Reference was made to a certain fault from the side of which all the coal had not been removed, and on being asked if that was where he would naturally expect to get a fire, he replied in the affirmative (*Q.* 1566–67). Even if all coal is removed from the sides of a fault there is left an element of danger of which Mr. Allott gave an instance. In this case it was affirmed the fault leader heated, the leader being composed of a glassy black carbonaceous shale (*Q.* 1615). Mr. Allott gave further examples of faults contributing towards spontaneous combustion, and he

said that faults passing through pillars in process of formation might be conducive to heating in the pillars (Q. 1696).

(B) *Mining Conditions.*

Methods of Working.—Several methods have been and are practised in working the coals of North Staffordshire, but on investigation it is found that each is simply a modification to meet local requirements and conditions of one or other of the principal systems common to every coalfield in Great Britain.

Generally speaking, the system most commonly practised is "Longwall" or some modification thereof. Figs. 10 and 10a are plan and section of a panel system which is commonly adopted. A pair of headings some 66 feet apart are driven in the solid coal to the boundary and are connected every 50 yards or so. At the inbye end a panel of longwall is opened out with three or four gateroads each with 50 yards of face. In this case, it will be observed that the faces are stepped to avoid extensive roof falls because of the tender nature of the roof. When a panel has advanced some 100 yards, another section is opened out. In this particular case the coal is holed at 4 ft. 6 ins. from the floor and taken in 6-ft. lifts, all got by hand labour. When the bottom coal is removed the packs are built under the top coal, the top coal is then cut by the sides of the packs and the timber removed. The top coal is then dropped into the waste and loaded out.

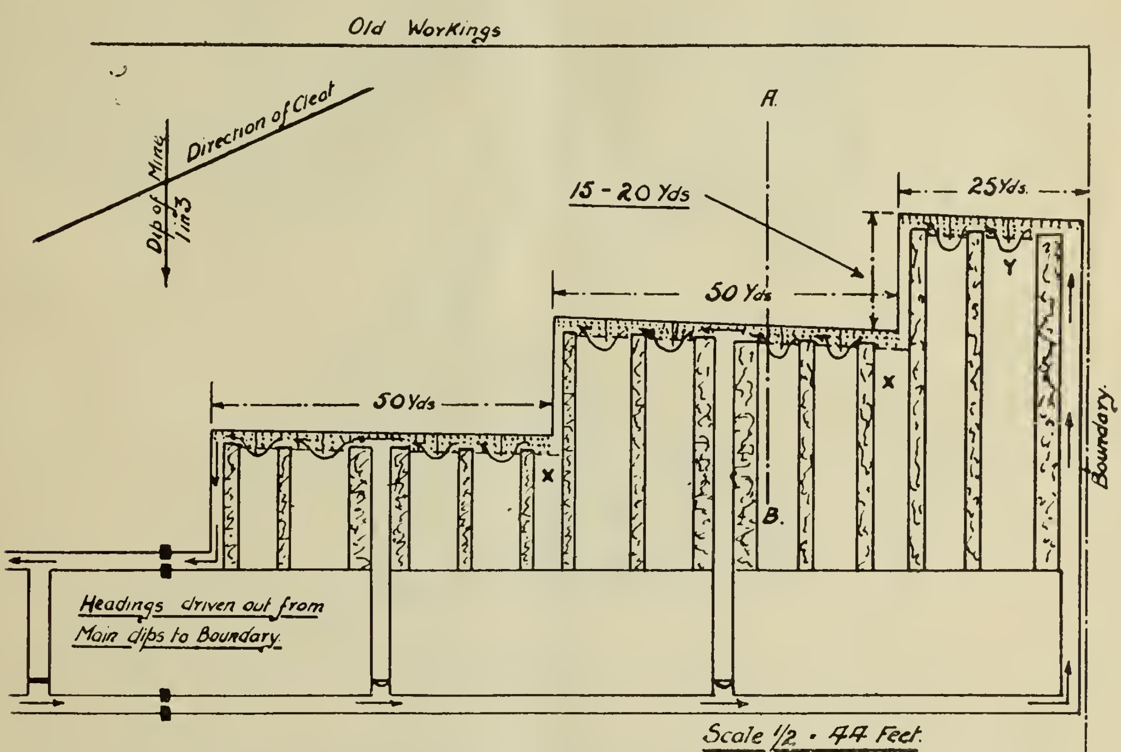


Fig. 10. Typical Plan of Stepped Retreating Longwall. Cockshead Seam. Mossfield Colliery.

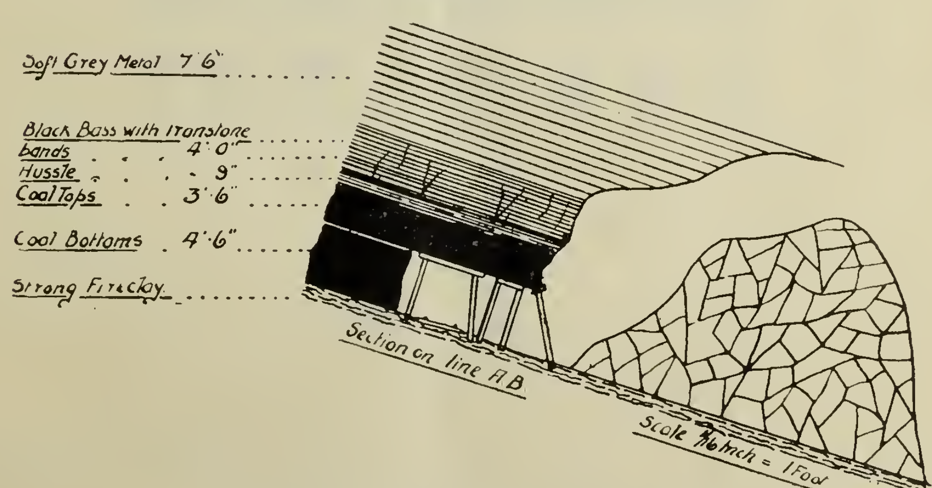


Fig. 10a. Section along Line A B.

This system may vary in detail according to the section of the seam, the condition of the roof, &c., but the broad principles are generally advocated for use in seams of medium thickness and moderate inclination which are liable to spontaneous combustion. The reasons for the adoption of some system of longwall in such seams were given by Mr. Henshaw as follows: "Longwall is more systematically worked than pillar and "stall, and consequently there is less coal likely to be lost in longwall than in pillar "and stall. In longwall the roof is better controlled than in pillar and stall."

With seams lying at steeper angles, however, other methods have to be adopted, and although witnesses differed as to the most suitable method it would appear that a system based on the "Bord and Pillar" method would best meet the situation. The area to be worked is divided, as far as possible, into panels approximately 140 yards by 160 yards. There are only two, or at the most three, roads into the panel, to allow of easy and effective damming off in case of the outbreak of fire. The panels are divided into pillars and the extraction of the latter is in descending order from the rise to the dip (*Q.* 2031). Mr. Daniels said that "the idea in working the panel is to "abstract the coal from the rise side first, and to allow the goaf to charge itself with "gas, and to keep the ventilation on the edge of the goaf, and not to allow any "oxygen to pass through or over it. In working only two drifts at once the object "is to keep control of the roof pressure by not having long uneven lines of goaf breaks, "and also that there may be only two or three stoppings to be closed" (*Q.* 2031).

Mr. G. P. Hyslop, Manager of the Shelton Coal and Iron Company's Collieries, mentioned a system of working which is termed locally "Post and Thirl," and which is illustrated by Figs. 11 and 11A. It was formerly adopted on account of the difficulty in obtaining suitable packing material (*Q.* 1178), but Mr. Hyslop said of it: "The objection to this system of work (which has been abandoned for some years) is "obvious, and it is clear that a large amount of coal in such a seam must be left "behind in stumps and pillars and in roof coal lost under fallen roof" (*Q.* 1182).

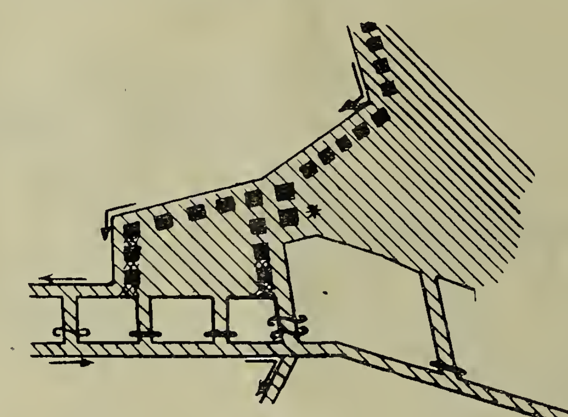


FIG. 11. GREAT ROW SEAM. POST AND THIRL SYSTEM (*SEAT OF FIRE).

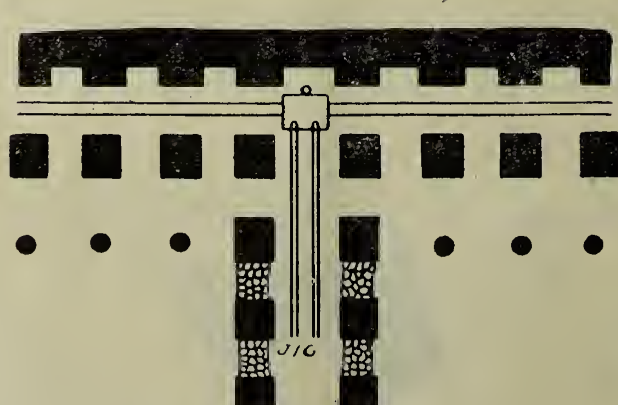


FIG. 11A. GREAT ROW SEAM. POST AND THIRL SYSTEM.

This system must inevitably conduce towards spontaneous combustion in any seam liable to self-ignition, and so far as we are aware it is not now practised.

Another system in vogue is that termed "Breastings." In this method the coal is worked by means of 12-yard breastings leaving 2 yard ribs of coal between each place, but Mr. Allott was insistent in condemning this system because of the intermediate goaves and ribs of coal which are thereby occasioned. In its place he strongly advocated the "Heading and drifting" system or Staffordshire "Pillar and stall" or "Rearer" method as being the most satisfactory method of working highly inclined seams subject to spontaneous combustion. The following is a brief description of the system, taken partly from Mr. Allott's evidence and partly from "*Modern Practice in Mining*."* The thicknesses of the seams worked, some eight in number, vary from 2 ft. 6 ins. to 8 ft. in section, and the depth from the surface at which they are worked from about 160 to 170 yards.

Rearer Method of Working.—The "Rearer" method of working is practised where the inclination of the seam is over 45 degrees. The seams are recovered by a pair of "cruts" or cross measure drifts, driven from an inclined roadway or from the shaft to strike the seam or seams; one at a higher level than, but not vertically above, the other. The lower crut serves as the haulage road and the upper as the return airway, so that the air crossings are of the type known as "natural" crossings, the two roads being divided by solid stone or coal as the case may be. (*See* Figures 12, 13 and 14.)

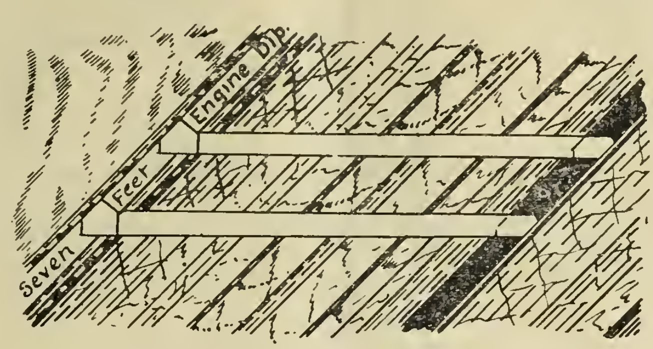


Fig. 12. Section showing "Engine Dip," "Cruts," and Levels in Rearer Workings.

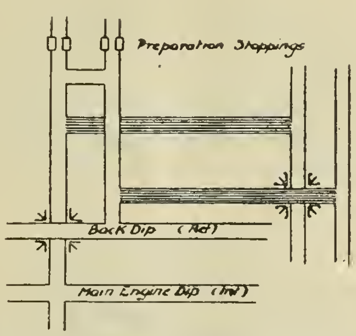


Fig. 13. Plan showing "Engine Dips," "Cruts," and Levels in Rearer Workings.

When the seam is reached it is opened out and "recovered" in the following manner. The royalty is divided into working strips by driving pairs of levels from the points where the coal is reached to the boundary, the distance between the levels being usually 230 yards. From these levels pairs of "dips" (or sometimes sets of three) are driven for 150 yards to the full rise of the seam at intervals of about 120 yards. From the dips on either side at intervals of about 10 yards are driven levels 60 yards in length. By means of holings between the levels the area to be worked is divided up into a panel of inclined pillars, the pillars being worked off from the rise downwards. The removal of the pillars is carried out in various ways depending on the stage of the work, and care is taken to maintain the face of the pillar workings at an angle of about 45 degrees from the line of full dip, as this is found to give the best results from the point of view of both safety and convenience. Barriers of a width varying from 80 to 150 yards are left between each panel and the one above it, these not being recovered until the deepest district has been worked out, when they are removed, commencing with the lowest and working upwards. This, according to Mr. Allott, is the principal objection to the system because, as he

* "*Modern Practice in Mining*," Vol. III., Methods of Working Coal. By R. A. S. Redmayne, K.C.B., 1914.

says, the barriers "must be sufficiently large to prevent them being broken and thus "allow leakages which must be dangerous." The loss of coal is heavy, only about 60 per cent. of the available coal being sent to the surface, crushed pillars, other sources of loss in working off the pillars, and portions of barriers impossible of recovery accounting for the loss. (Figure 14 illustrates the plan of a mine worked by the "Rearer" system and in common with the previous two figures is taken from "*Modern Practice in Mining.*")

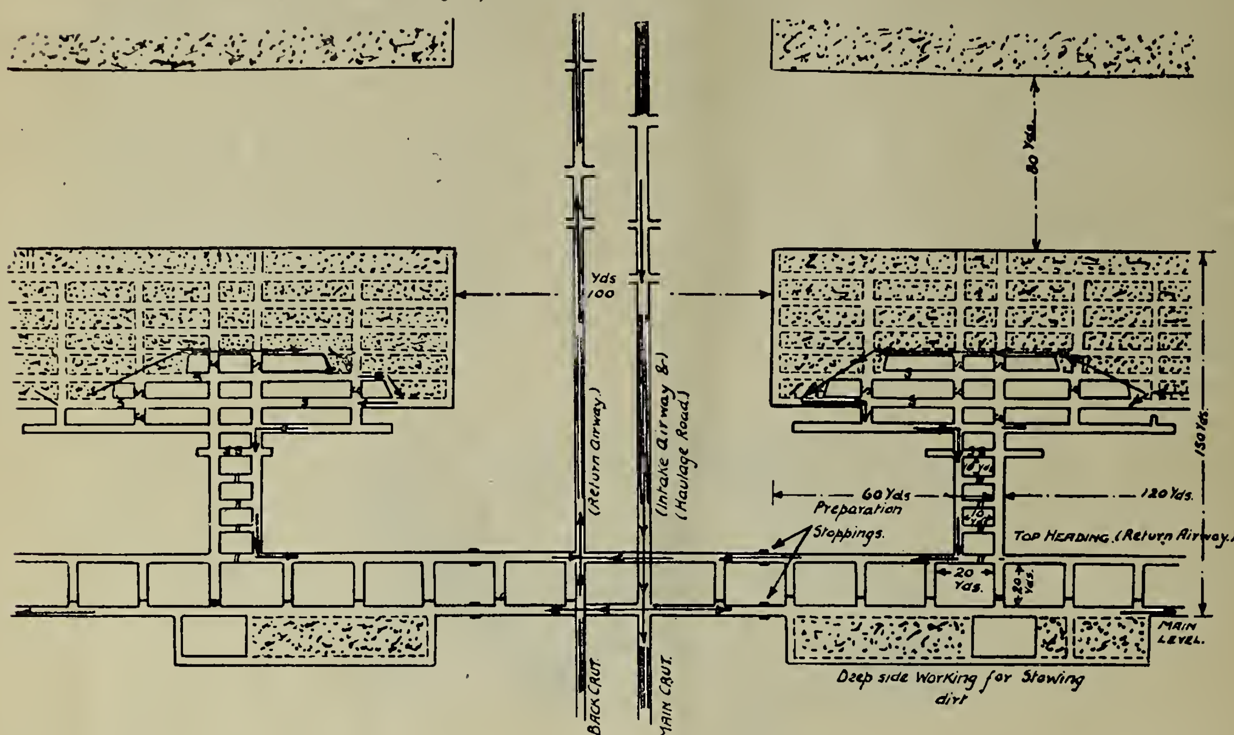


FIG. 14. PLAN OF REARER WORKINGS.

It should be noted that by this method also the coal is extracted from the rise to the dip, and the goaf above is allowed to fill with gas, "thus preventing "spontaneous combustion from taking place." (*Q.* 1648 and 1663.)

The system finally adopted must to a great extent depend on experience, as extraneous circumstances may nullify the best design. Fig. 15 is a case in point.

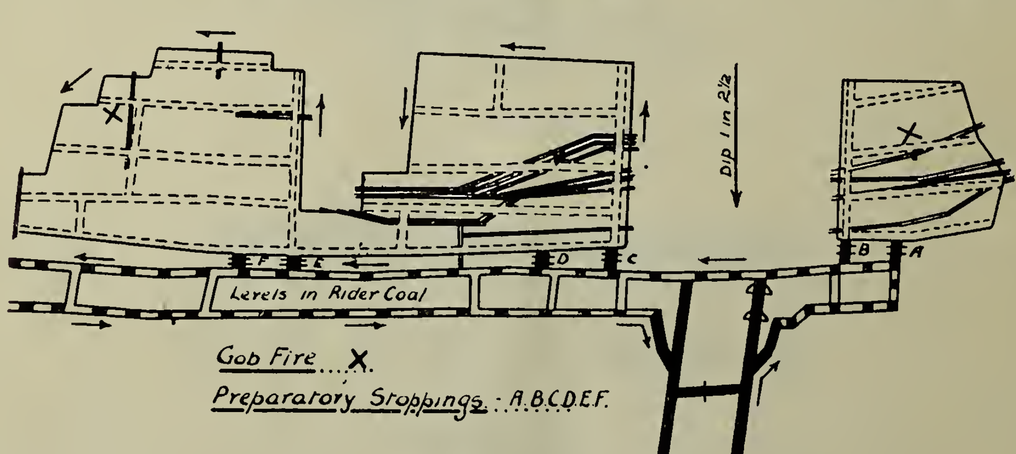


FIG. 15. LONGWALL PANEL SYSTEM.

It illustrates a carefully designed longwall panel system of working, which failed owing to roof faulting, leading to excessive loss of coal in working. The development roads were stone drifts with levels in the Rider coal. The panels were small and quickly worked, but fires followed in each case (*Q.* 825).

Mr. Allott laid down certain general principles which he advocated as applicable to all mines subject to spontaneous combustion, and these we quote in full :—

"(1) The districts should be as small as possible and worked out quickly.

"(2) The minimum amount of ventilation should be passed through them, only sufficient to keep the faces and goaf edges clear of gas.

"(3) Avoid intermediate goaves between the intake and the working faces.
"(4) Have the minimum number of openings in each district and always have preparation stoppings in readiness for building off.
"(5) Clear out all the coal as far as possible, and particularly in the neighbourhood of faults.
"(6) Keep the face as level as possible in the heading and drifting system of working.
"(7) The stoppings should not be built close up to a main roadway, but kept back a few yards so that they can be examined for leakages.
"(8) All districts should be sealed off when finished, whether there has been trouble from gob heats or not" (*Q.* 1665).

It will be noted that in the foregoing descriptions of methods of working mention has been made of a practice involving the systematic "flooding" of the goaf with gas with the object of "drowning" fires and heatings arising from the spontaneous combustion of the coal. At first sight this would appear to be a most reprehensible and dangerous procedure, inasmuch as the gas employed is the ordinary marsh gas or fire damp emanating from the coal. It should be understood that this system is only in use when the coal is being exhausted downwards and when the inclination is fairly steep and regular. Various witnesses were interrogated as to the practice, and its practicability was unanimously agreed on. In North Staffordshire, at any rate, it is regarded with great favour. *Mr. Henshaw*, on being questioned as to the danger of explosion resultant on the flooding of the goaves with gas, replied: "It is a plan open to a good deal of question and debate, and people who are not "acquainted with North Staffordshire mining and who come into the district from "other parts of the country and find that we are purposely filling our rise wastes "with gas are alarmed, but as they become familiar with North Staffordshire "methods they are converted to that plan." *Mr. Hyslop* said: "In pillar work in "seams known to be liable to gob-fire, the practice of ensuring that the gob is "covered by fire-damp as the face retreats has been worked successfully for many "years, and in my experience it has been satisfactory. The obvious risk of allowing "fire-damp to approach the working-places so nearly may be exaggerated. As "compared with the older practice of drawing off the return ventilation on the rise "side of the drift, I believe it to be in fact much safer. In the latter case perfect "ventilation of the gob is impossible, accumulation of gas in the gob cannot be "prevented, and the development of a gob-fire under such conditions in such seams "as the Bullhurst is merely a matter of time, and its detection is made more difficult." On being asked if he could suggest any method of working that particular seam to reduce the liability to gob-fire other than by the system of allowing the goaves to be charged with gas, Mr. Hyslop said: "No; short of the untried remedy of hydraulic stowage" (*Q.* 1286).

Mr. Allott declared it to be the universal custom in the district "and the only "one by which we can feel safe at all in working these seams subject to spontaneous "combustion." The faces and goaves for at least 20 yards back therefrom are of course kept free from the gas.

Since the evidence that we have just quoted was given an explosion occurred on 12th January 1918, at the Minnie Pit of the Podmore Hall Colliery in the Bullhurst Seam under similar conditions to those described. *Mr. W. Walker*, His Majesty's Chief Inspector of Mines, reported* on the disaster on 31st May 1920, and in his "Summary of Conclusions and Recommendations" he says: "There is no doubt, I "think, that the 'Bull-dog' stone in the goaf fell just prior to or about the time the "explosion occurred, and it may be that the sparks and flashes caused by its breaking "and falling ignited the gas in the goaf. If this theory is the correct one, and it is "held by the management and several other witnesses, working from the top and "allowing the goaf to become charged with fire-damp *where the gradient is less than* "1 *in* 5 is attended with considerable risk. The goaf in these circumstances should, "I think, either be kept ventilated or packed. It would be safer, where the "conditions are such as to allow of its being done, to work the coal from the bottom "and fill the goaf with packing or water."

Coal left in Wastes.—If it is granted that isolated heaps of coal under suitable conditions will fire of themselves, then is it axiomatic that the greater the quantity of

* "Report on the Causes of and Circumstances attending the Explosion which occurred at the Minnie "Pit of the Podmore Hall Colliery on Saturday the 12th January 1918." By W. Walker, C.B.E., His Majesty's Chief Inspector of Mines, 1920 [Cmd. 810].

coal left behind in the waste workings the greater will be the liability therein to spontaneous combustion if the same conditions are existent. It has been pointed out that certain systems of working the seams result in a greater percentage of extraction than others, and again that the quality of the coal, the presence of faults, the inclination of the seam and the nature of roof and floor have each a bearing on this part of the subject.

Witnesses were questioned as to the proportion of coal left, and their estimates varied from 5 per cent. in longwall with a good roof to 16 per cent. in longwall with a bad roof. In any district, when working seams by the longwall method, there is usually less natural loss of "small" coal and less loss of "whole" coal in the shape of corners, "punches" and thin ribs left against faults (*Q.* 640). With the "heading and drifting" system Mr. Allott reckoned on getting a 75 per cent. extraction (*Q.* 1676), but he also said that in the Seven Foot Banbury he lost 40 per cent. of the coal in barriers and crushed pillars.

Crushing of Pillars.—As the major portion of the North Staffordshire coalfield is worked by the longwall system, the crushing of pillars does not enter so largely into the question as in a pillar and stall district. It is a fact, however, well known to all mining men, that pillars must be designed both in size and shape to conform to the conditions obtaining in each particular seam. As the depth increases so does the danger of crushing, by reason of the weight of the superincumbent strata.

Several witnesses gave instances of fires occurring in crushed pillars of coal, in fact, Mr. Hyslop went so far as to say that "the simplest way of producing a gob-fire "is to leave a pillar of coal" (*Q.* 1330).

The bord and pillar system was universally practised in the North Staffordshire coalfield 40 years ago, but has since been almost entirely abandoned in favour of longwall because of the creep and crush incidental to the former method. In the "breasting" system it is customary to leave ribs of coal between the various breasts, and Mr. Allott condemned the system on this account. In his evidence he quoted several cases of spontaneous combustion which had been determined as being directly due to crushed pillars and ribs, both in the "breasting" and in the "heading and drifting" systems.

Packs.—During the process of the extraction of the coal means must be taken to protect the workers, and this is done in various ways, according to the method of working involved. In the pillar and stall system, when working "in the solid," timber alone is used, except on very rare occasions, but in longwall workings, in addition to timber props, walls built of the most suitable material available are required both for protection of the workers and for the control of the roof fracture. Too much emphasis cannot be placed on the importance of good packing, but it is impossible to generalise as to what shape and size the pack walls should take. These will depend entirely on the available materials and on the details of the method of working, *e.g.*, distance between gateways, width of roadways, character of the top, and will vary in almost every colliery and every seam. Fig. 16 illustrates the system of packing adopted by Mr. Hyslop in his longwall workings. The roof coal is got down in the wastes, and the packing material is obtained almost solely from the roof marl broken down between the packs. The roof coal in the roadways is allowed to stand as long as possible, and the roads are not ripped into the overlying marl until some time after the face has advanced; the débris from the ripping is not invariably stowed in the face, but is sometimes sent out of the pit (*Q.* 1178).

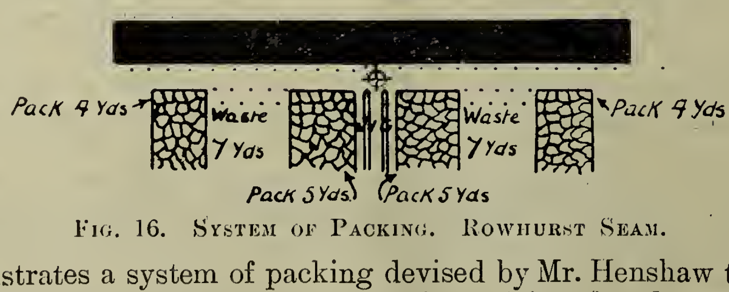


Fig. 16. System of Packing. Rowhurst Seam.

Fig. 17 illustrates a system of packing devised by Mr. Henshaw to secure uniform settlement and freedom from leakage. It consists of interlaced continuous chocking placed on the roadside. This packing was used in the longwall district illustrated in Fig. 15, and according to Mr. Henshaw it answered its designed purpose admirably, and cost very little more than stone packing (*Q.* 825), but as it involves the use of timber in the packs, it seems to us inadvisable in seams liable to spontaneous combustion except as referred to on page 108, IV. (*c*).

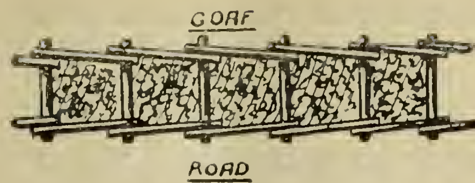


FIG. 17. TALK O' TH' HILL COLLIERY. CONTINUOUS CHOCK PACKING.

In the seams of North Staffordshire where the longwall method of working is practised, it would appear to be common to build the packs under the top coal, and here as elsewhere to make the walls of the largest stones procurable, filling in the space between the walls with the smaller stones and dirt usually obtained from the fallen waste or the gateroad ripping. Sometimes there is not a sufficiency of non-inflammable material available for the purpose, and recourse is had to small or inferior coal, or to the carbonaceous shales that abound in the district (*Q.* 748, 1157, 1161). All witnesses admitted that this procedure is to be deprecated, being conducive to self-heating in the packs, and should be avoided. It was pointed out to us, on the other hand, that it was better to pack well and risk, to a certain extent, the possibility of spontaneous combustion within the packs rather than to advance the face indefinitely with the goaf insufficiently packed, in the latter case to incur the consequent dangers attendant on such procedure. The weight of the evidence from North Staffordshire witnesses, however, confirms us in the view that every endeavour should be made to keep the packs as free as possible of all combustible matter.

In North Staffordshire few cases have been noted of fires occurring in the roof coal overlying the packs, but here again there is an undoubted danger of such coal being crushed with the possibility of ultimate fire. In some cases the policy of keeping packs clear of coal is perhaps a counsel of perfection, but wherever possible such a course should be followed.

LEAKAGE OF AIR ACROSS GATEWAYS, THROUGH PACKS OR WASTES. — In the collieries of North Staffordshire liable to spontaneous combustion it is customary, as far as possible, to control the ventilation and prevent circulation and leakage of air through the packs, goaves, pillars and disused workings. There is, however, another school of thought in the district, which teaches that a brisk ventilation of the goaves will prevent ignition by carrying away the heat as fast as it is generated (*Q.* 469–470). In Mr. Henshaw's opinion this latter course is rarely practicable, in view of the resistance the air would encounter on account of the broken and inaccessible nature of the goaves (*Q.* 470). He did not consider that ventilation ought to be allowed where a man cannot travel and inspect its effect (*Q.* 473). Comparatively little evidence on this part of the subject was given, but *Mr. Johnson* declared that "the less leakage into the waste the better, and less "would be the danger" (*Q.* 189), and he stated further that "we attribute our "freedom from gob-fires to excluding the air from the goaf" (*Q.* 268). *Mr. Hyslop* stated that "In those instances in the Great Row longwall workings where "spontaneous combustion has taken place, the seat of the fire has nearly always "been at some point where there has been irregular subsidence of the roof coal and "the superincumbent strata permitting leakage of air into a waste. This is more "likely to occur in the first pack which is put against the solid rib of coal upon "starting a longwall drift." Fig. 18 illustrates such fracture of the roof (*Q.* 1178).

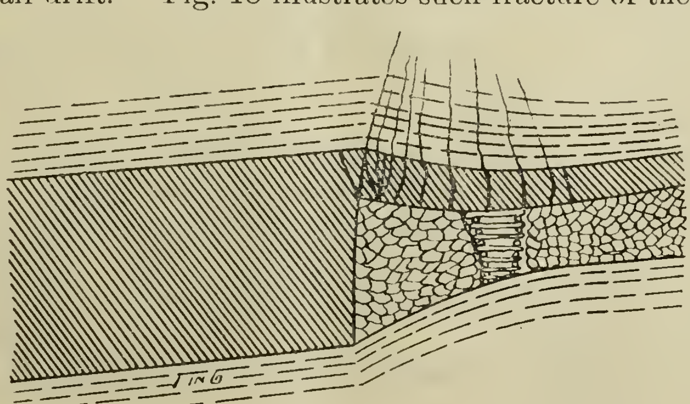


FIG. 18. GREAT ROW SEAM. FRACTURES ALLOWING LEAKAGE OF AIR IN WASTE AT COMMENCEMENT OF LONGWALL WORKING.

Opinions differed as to the efficiency of sealing off the gateroad packs by means of plastering, and Mr. Hyslop after trial decided against such procedure as being quite ineffectual (*Q*. 1400).

TIMBER LEFT IN THE WASTE.—We attached, and do still attach, the greatest importance to the question of the relationship of timber left in the goaves and the outbreak of gob-fires, and we interrogated each witness on this point. The result of our investigation was to impress us with the extreme advisability of extracting all timber wherever possible from the goaves of seams liable to spontaneous combustion. Almost every witness admitted that timber was a contributory cause to self-heating, and as in seams possessing a tender roof the loss in timber is very considerable, the danger of fire is increased in such cases. Mr. Henshaw advised us that, in addition to waste timber, chips of paper, brattice cloth, grease, and other combustible matter should not be left or thrown into the goaf (*Q*. 824). Cases were quoted where the heating had been accompanied by a distinct smell of burning timber (*Q*. 2043).

The self-heating does not arise in the timber itself, but the timber prevents the close settlement of the falling roof, and occasions cavities in which the oxygen of the quiescent air attacking the coal sets up heat, and the point of inflammation of the timber being lower than that of the coal, the former is probably the first to ignite, and so the fire is started.

(C) *Preventive Measures.*

(i) *The Methods in operation for Preventing Gob-fires.*

Although it may be that the coal seams in North Staffordshire which are the most liable to spontaneous combustion do not differ in essentials from seams in other districts, local tradition and custom are responsible for the adoption of at least one special method designed to prevent the initiation or propagation of underground fires. We refer to the "drowning" of the goaves with non-oxidising gases (usually firedamp), a system already described on page 41.

Apart from this, the precautions taken are more or less as general in conception and adoption as those in use throughout the other coalfields in the United Kingdom. There are certain considerations which enter largely into the framing of local rules and regulations imposed on the various officials at each colliery that are common to all, and the evidence of the North Staffordshire witnesses was remarkably unanimous in this respect. It is of interest to note how the majority of the witnesses laid great stress on the importance of attention being paid to details which, in themselves, might be considered by many to be too trivial to warrant action. Thus *Mr. Hyslop* remarked : "The main conclusion I have come "to after twenty years' experience in dealing with cases of spontaneous combustion "in North Staffordshire is that a considerable degree of safety, if not immunity, "can be obtained by careful attention to minor and sometimes apparently insig-"nificant details" (*Q*. 1187).

Generally speaking, the methods practised in the mines of North Staffordshire for the prevention of underground fires, and advocated by the officials of these mines, are as follows :—

i. Prevention, as far as possible, of loss of coal in the wastes, and, combined with this, the extraction of the small and inferior coal which is normally left behind.

ii. Complete control of the ventilating current; prevention of air circulation through packs, goaves, pillars and disused workings.

iii. Complete extraction of timber and of all other combustible foreign matter.

iv. Efficient packing to prevent leakage of air. Exclusion of combustible matter in the construction of packs, and the exclusion of cross-walls within the packs.

v. Provision of special methods of working which vary in accordance with the local conditions.

vi. Division of the colliery into small districts with a minimum number of intake and return roadways.

vii. Provision of preparatory stoppings, the positions of which are carefully chosen.
viii. The sectional area of all airways kept as large as possible.
ix. The system of ventilation arranged to avoid a high water-gauge and high air velocity.
x. The use of soft wood chocks to secure uniform settlement of the roof, (Mr. Henshaw, *Q.* 823).
xi. Encouragement of assiduity on the part of officials in detecting the faintest smells of "gob-stink" with a view to preventing further development of heating (Mr. Hyslop, *Q.* 1187).
xii. Sealing-off of all disused districts and roads.
xiii. Immediate and frequent investigation of any unusual occurrence observed in the goaves, no matter how trivial.

It will be seen later how far these precautions agree with the methods adopted in other districts.

(ii) *The Methods in operation for Dealing with Gob-fires when they occur.*

Before dealing with these methods it is essential that some general idea should be given as to the symptoms accompanying an outbreak of gob-fire, and of the means taken to detect and locate the fire. Heating of the gob is often discovered in the first instance by the peculiar and characteristic odour known as "gob-stink." Mr. Henshaw describes the smell in its incipient stage, as "sour fermentation, " decaying vegetation, rotten timber, a taint of onions or garlic." It progresses to a " paraffin, benzol, naphtha, or tarry stage, similar to the smell one gets near the " distillery of a coke-oven plant. It then grows more pungent and irritating to the " nostrils and throat, and is accompanied by visible vapour from the expelled " moisture. Carbon monoxide and carbonic acid may be detected, oxygen is low, " and lamps burn dimly. Its progress is now more rapid, and smoke is shortly " smelt and seen. Ignition follows quickly. The time elapsing between the first " indication and ignition varies greatly. In one case where the whole process was " carefully observed the period was 52 hours, and in another 6½ weeks, from the " first faint smell to the appearance of smoke" (*Q.* 824). The symptoms, as described by Mr. Henshaw, were given in more or less the same detail by other witnesses, but it was pointed out to us that circumstances might be such that one or other of the stages might be missed. For example, a ventilating current penetrating to the seat of the heating could be sufficiently strong to carry off, dilute and dissipate the early products of combustion. Extraneous substances not in any way connected with a fire, such as tarred brattice cloth, might give off a similar smell to that of gob-stink, and the latter escape notice. Officials or workmen might detect a smell and carelessly fail to report the occurrence. Men trained in the detection of gob-fires are seldom mistaken as to the meaning of the smell, and they can usually tell what stage the heating has reached. Another and frequently attendant symptom is the deposition of moisture on the roof and sides in the vicinity of a heating. Mr. Daniels stated that he frequently felt a "sensation of unusual dryness in the atmosphere." He had also experienced "the appearance of a thin mist, and on one occasion a " distinct smell of burning sticks or wood" (*Q.* 2035). Witnesses were asked whether thermometers would be of material assistance in the early detection of fires, but no one was favourably impressed by his experience in that respect, though several advocated their use for the purpose of registering the progress of heating that might develop into an outbreak.

The practice pursued in some other districts of digging out fires or heated coal has few adherents in this district, especially at those collieries where the seams are highly inclined or where the roof is tender. Of this *Mr. Henshaw* said: "Loading " out may, under certain circumstances, be successful, and conditions favourable to " loading out are: Near point of access to the seat of heat, freedom from fire-damp, " good roof, and prompt action before ignition." He maintained, however, that the safest way of combating an outbreak in a fiery mine where there are continual difficulties in connection with gas, as soon as there is the slightest suspicion of heating, is to commence stowing all roads into the suspected area, and to efficiently dam off the district (*Q.* 961). In this view he was supported by the majority of witnesses and this is the procedure universally practised throughout the coalfield.

The serious delays which would be involved had stoppings to be prepared after an outbreak are so obvious that it is hardly necessary to say that in collieries liable to spontaneous combustion preparations are invariably made for the erection of preparatory stoppings.

Figs. 19 and 19A illustrate a type of stopping put in by Mr. Hyslop in an instance where the roof was cut down to a great height. The frame consisted of circular joists 8 ft. 6 ins. in diameter, and 8 ins. by 6 ins. section. Round this frame a ring of concrete was packed, and behind this, loose stones, bricks, and timber were packed up to the broken strata. According to Mr. Hyslop the great pressure tightened the material and made it almost as solid as the strata (*Q.* 1187).

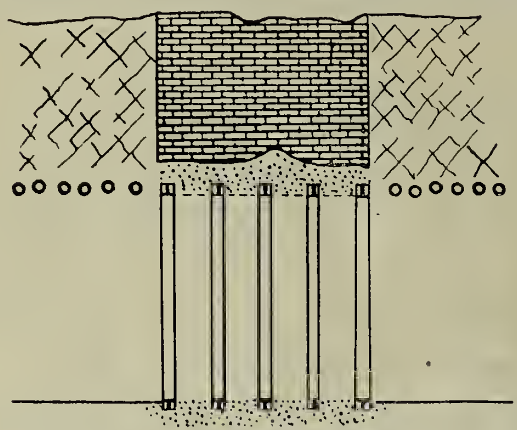


Fig. 19.

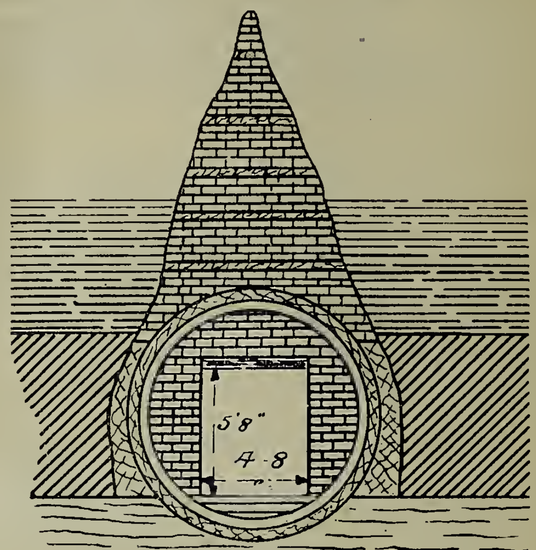


Fig. 19A.

Type of Stopping for use in Tender Ground (*Q.* 1187).

Figs. 20 and 21 show types of preparatory stoppings in common use in the collieries of the Shelton Coal and Iron Company.

Elevation. Plan.

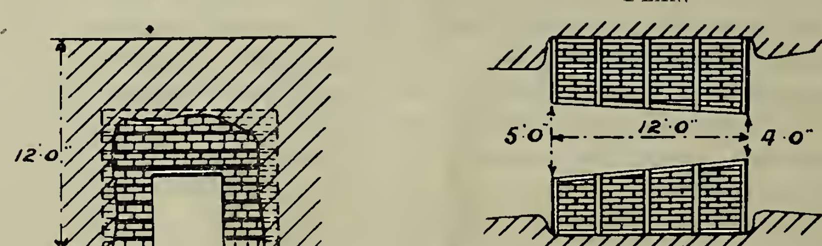


Fig. 20. Preparatory Stopping (*Q.* 1187).

Plan. Elevation.

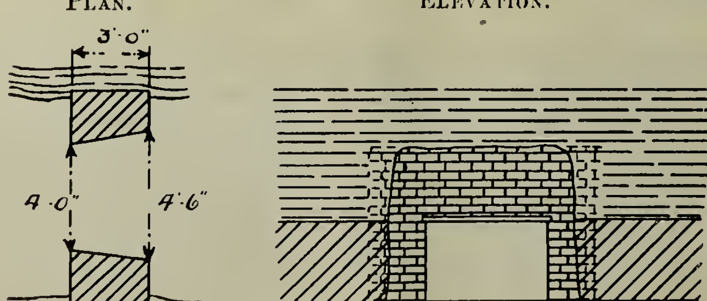


Fig. 21. Preparatory Stopping (*Q.* 1187).

In support of his advocacy of preparedness for damming off districts in case of fire Mr. Henshaw gave examples of various types of stoppings, both preparatory and permanent, a few of which are given below. Fig. 22 is an illustration of an emergency stopping from 4 to 6 yards thick, according to the area of the road. Good stone walls are built at the back and front, and props set against them to prevent slipping. An opening some 4 ft. square is left in the stopping to allow ventilation to be maintained during the work of construction, and this opening is finally closed by means of bags of sand, the interstices being tightly rammed with loose sand. "Pack stoppings of this description can be put in very quickly by " ordinary workmen, and they can be made thoroughly efficient for the immediate " purpose" (*Q.* 824).

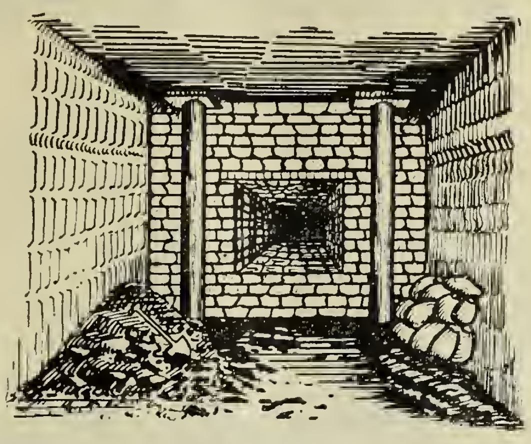


FIG. 22. TALK O' TH' HILL COLLIERY. EMERGENCY STOPPING (*Q.* 824).

Fig. 23 is that of an emergency stopping composed of posts and rails packed with sand or fine dirt.

"By selecting a manhole on one side of the road, and making another opposite, laying the posts and rails across, closely together, filling the spaces with small rubbish or sand, and making good at the top with long split timber as wedges, a good job can be made in a short time" (*Q.* 824).

FIG. 23. TALK O' TH' HILL COLLIERY. EMERGENCY STOPPING (*Q.* 824).

Fig. 24 illustrates a type of preparatory stopping which Mr. Henshaw considered satisfactory in very bad ground (*Q.* 824), and which he used in the district illustrated in Fig. 15.

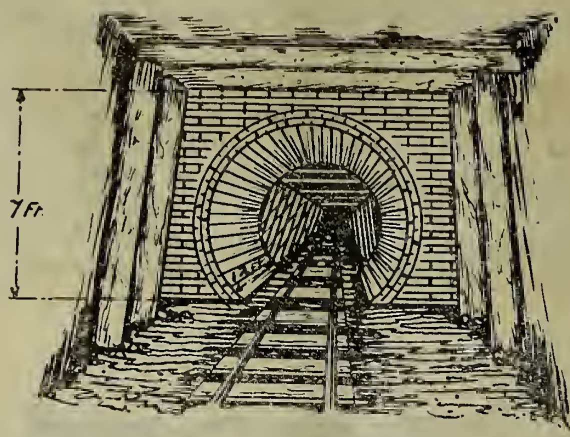


Fig. 24. Talk o' th' Hill Colliery. Circular Brickwork Preparatory Stopping.

Fig. 25 is another of rather more elaborate type.

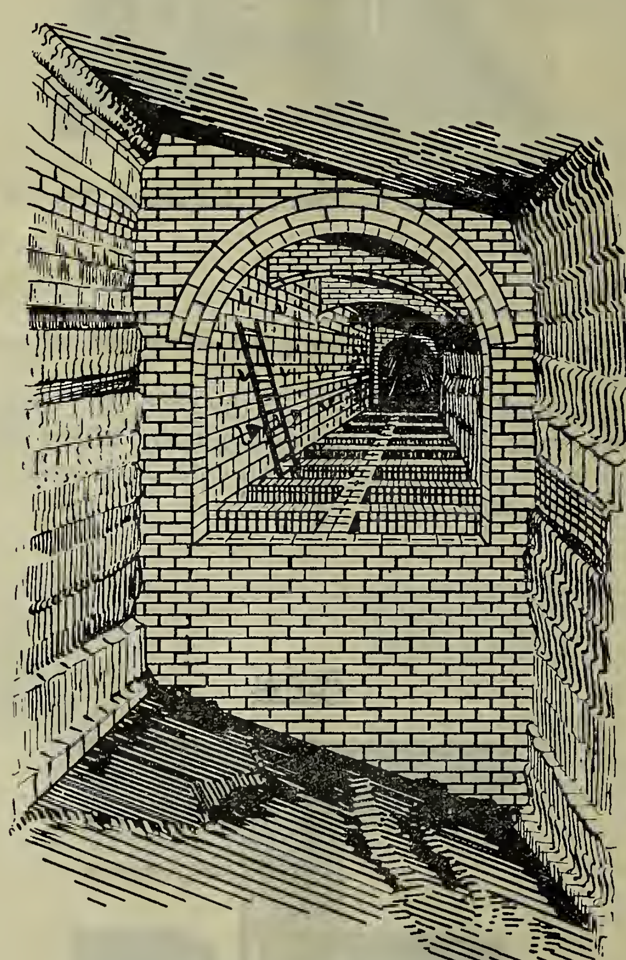


Fig. 25. Talk o' th' Hill Colliery. Arrangement for a Gob-fire Stopping.

With regard to permanent stoppings *Mr. Henshaw* said: "They should always "be a first-class job. The brickwork should be as good as in the case of dams for "water. It should extend well into the sides, roof and floor, and every brick should "be floated in mortar. Cross joints are particularly liable to be neglected, and the "slightest leakage either through the walling or strata may render the work "useless, and all the efforts futile. Repairs should be as carefully attended to, and "a system of regular inspection by competent men instituted" (*Q.* 824 and Fig. 26).

Fig. 26. Talk o' th' Hill Colliery. Permanent Stopping.

2. SOUTH STAFFORDSHIRE.

Introductory.

The South Staffordshire coalfield is distinctly and definitely divided into two main sections by an east and west fault called the Great Bentley Fault, which probably has a downthrow to the north of about 120 yards. The southern portion of the field is peculiar, inasmuch as over the greater part of its area extends the famous Thick or Ten Yard coal seam, ranging in thickness from 24 feet to 42 feet, but having an average thickness of 25 or 26 feet. The coalfield, as a whole, is again subdivided into a visible field and a hidden field by two great faults coursing north and south, the one on the eastern side, the other on the western side of the "exposed" field, and the coal on either side of these two faults (that is, in the hidden field) is found to be unaltered as to thickness, but at a much greater depth. South of the Great Bentley Fault, too, the coal measures have been subjected to such geological disturbances and pressures that the coal seams are found to be faulted and distorted to a greater degree than in the north, rendering mining conditions much more difficult. North of the Bentley Fault the coal seams lie at a greater depth than to the south, and here the Thick coal has been altered and split up into several distinct and isolated beds. In each of the districts one or more of the seams is liable to spontaneous combustion, and evidence was taken in respect of this liability both in the Thick coal occurring south of the Great Bentley Fault and in various seams lying to the north thereof.

The Thick Coal of South Staffordshire.

(A) *Geological Conditions.*

As has been indicated, the principal seam (in the south) is an abnormally thick bed of coal which occupies a considerable area, though it is not consistent within that area as to thickness or quality. The following sections are taken from the evidence, and are illustrative of this inconsistency. It should be noted that these sections are all below the average for the coalfield.

Thick Coal, Sandwell Park Colliery.

(From evidence of Mr. Bailey.)

	Ft. ins.	Ft. ins.
Rock and Bat:		
Rhoves or Rooves - - - - -	2 0	—
Parting - - - - - -	—	—
Top Slipper - - - - - -	2 0	—
Parting - - - - - -	—	—
White Coal - - - - - -	2 0	—
Parting - - - - - -	—	—
Lambs - - - - - -	1 6	—
Parting - - - - - -	—	—
Tow Coal - - - - - -	1 6	—
Parting - - - - - -	—	—

	Ft. ins.	Ft. ins.
BRAZILS	2 6	—
Parting	—	—
FOOT COAL	1 0	—
Parting	—	—
JOHN COAL	1 0	—
Parting	—	—
SLIPS	2 0	—
Parting Hardstone	—	0 6
STONE COAL	1 6	—
Parting	—	—
PATCHELLS	1 0	—
Parting	—	—
SLIPPER AND SAWYER	4 0	—
Bat	—	0 3
BENCHES	2 6	—
	24 6	0 9

Thick Coal, Hamstead Colliery.

(*From evidence of Mr. Holland, Q.* 7624.)

———	At Shaft.		East Workings.			
	Ft. ins.	Ft. ins.	Ft. ins.	Ft. ins.	Ft. ins.	Ft. ins.
REEVES COAL	2 0	—	1 2	—	—	—
TOP SLIPPER COAL	1 8	—	1 9	—	—	—
LAMBS AND WHITE COAL	4 5	—	4 0	—	—	—
Parting	—	0 1	—	—	—	—
BRAZILS AND LOW COAL	4 4	—	4 0	—	—	—
Bat	—	0 6	—	—	0 9 to	1 3
SLIPS COAL (inferior)	1 9	—	0 6 to	0 9	—	—
Parting	—	—	—	—	0 6 to	1 0
Bat	—	—	—	—	—	—
STONE COAL	2 6	—	1 6 to	2 0	—	—
Bat	—	0 6	—	—	1 0 to	4 0
SLIPPER AND SAWYER COAL	4 4	—	2 6 to	3 0	—	—
Bench Bat	—	0 8	—	—	0 6 to	2 0
BENCHES	1 3	—	1 0 to	1 6	—	—
Total Thickness	22 3	1 9	16 5 to	18 2	3 9 to	8 3

Thick Coal, Cakemore Colliery.

		Yds. ft. ins.
Hard Sandstone		10 0 0
Black Bat		1 9
	Ft. ins.	
Top Section :		
ROOVES	1 0	—
Parting	—	—
TOP SLIPPER OR WHITE COAL	3 6	—
Bat	—	0 1
JAYS	0 11	—
Parting	—	—
LAMBS	0 11	—
TOW COAL	1 4	—
Parting	—	—
BRAZIL COAL	1 2	—
Parting	—	—

		Ft. ins.	Ft. ins.
Foot Coal		0 11	—
Black Dirt and Bastard Fireclay		—	1 6 to 6 0
Bottom Section :			
Bat		—	0 6
Stone Coal	Coal	0 4	—
	Hard Stone	—	0 2
	Coal	1 0	—
	Bat	—	0 2
	Coal	0 11	—
	Patchells Bat	—	0 2
Coal (Patchells)		0 8	—
Bat		—	0 4
Bottom Sawyer		4 3	—
Rock and Bastard Coal		—	1 0
		16 11	

Various anticlines cause the measures to alter quickly in inclination, and faults, together with intrusive sheets and dykes of basalt, increase the difficulties. The coal is not found as a solid bed of unvarying quality, but is composed of a number of layers of different qualities and characteristics, separated by "partings" varying from a layer of fine coal to several feet of dirt. Several of these "partings" contain carbonaceous matter, and the roof overlying the top coal is sometimes composed of a carbonaceous shale (*Q.* 7625). Certain portions of the Thick Coal contain pyrites occurring in layers, but it was pointed out to us that the top coal is the most free from pyrites, and also the most prone to spontaneous combustion (*Q.* 2826). The coal is not very friable, and it was stated by *Mr. L. Holland*, General Manager of Hamstead Colliery, that the moisture content did not exceed 6 per cent. The roof of the seam is a carbonaceous "bat"* a few inches in thickness, over which lie several feet of bind or shale sometimes fairly hard and compact, and above this is a bed of "strong" sandstone some 14 feet thick. The floor for the most part consists of fireclay. Resulting from the strong roof and fireclay floor, much trouble is experienced by reason of the floor lifting in the workings with attendant crushing of the coal. The depth of the Thick Coal from the surface varies considerably, and it is stated that, whereas in the deeper pits the liability to spontaneous combustion is more confined to the roads driven in the solid coal, fires are more or less restricted to ribs and pillars and to the goaf in the seam where it exists at shallower depths (*Q.* 2841). Witnesses agreed generally that faults were conducive to fires principally because coal is almost invariably left against the main slip of the fault. This coal becomes broken and fissured, and air getting into the breaks results in heating.

(B) *Mining Conditions.*

Methods of Working.—When it is remembered that the Thick Coal of South Staffordshire has been worked for at least 300 years, and that the area of the exposed coalfield is not large, it will be seen that many of the mines are in ground already worked to some extent.

Because of the liability of the Thick Coal to spontaneous combustion, special methods of working have had to be adopted, these being either modified Longwall, or the Square or Wide Work methods.

In the latter method the coal is worked out by a series of rectangular chambers, separated from each other by coal ribs some 8 yards wide, support for the roof of the chambers being afforded by a system of pillars of coal 6 to 8 yards square. The coal is not removed in one operation but in several, and long periods may elapse between working the "whole" (as the first operations are termed) and the final extraction of the ribs and pillars.

* A compact black carbonaceous shale which splits into fine laminæ.

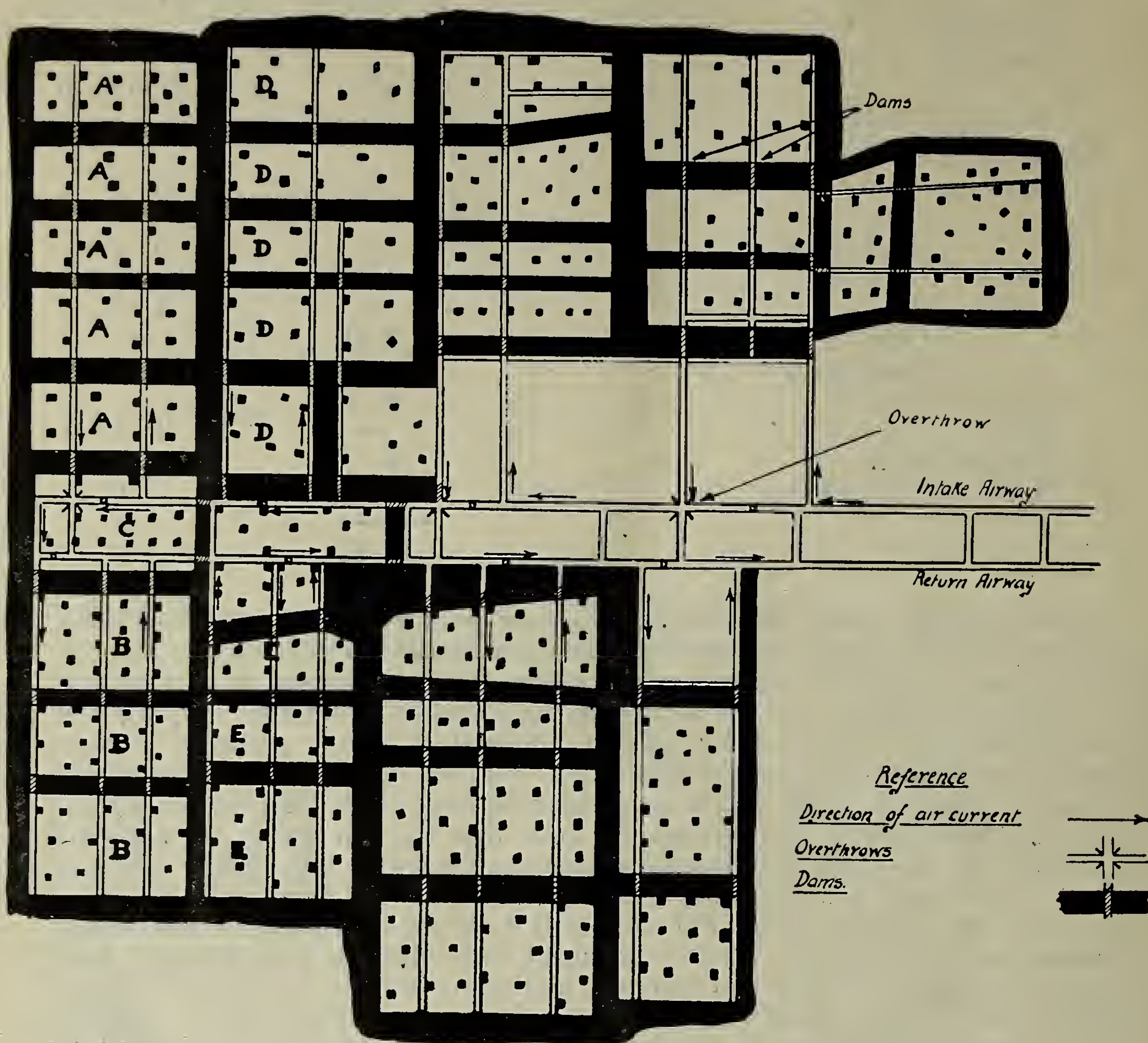


FIG. 27. THICK COAL WORKINGS.

Fig. 27, illustrating the present method of working the Thick Coal, either in shallow or deep mines, was put in as evidence by the late *Mr. F. G. Meachem*, the well-known South Staffordshire mining engineer. In this case the pit is divided into districts, only one of which is shown, and each district is subdivided into panels which are worked and ventilated as shown on the plan (*Q.* 2876). In the shallow workings the ribs and pillars are recoverable, but in the deep workings beyond the boundary faults it is problematical whether a large proportion may not be irrecoverable by reason of the enormous pressure exerted on the pillars.* Mr. Holland stated that he worked out about 60 per cent. and left 40 per cent. in the ribs and pillars (*Q.* 7635), but he admitted later that in certain cases a less amount than 60 per cent. was got (*Q.* 7646).

In certain areas of the southern portion of the coalfield the Thick Coal splits up and a method of working approximating to Longwall is adopted. Here, again, a district is divided into panels, which are separated from each other by barriers of coal 50 yards or so in width, and in this, as in the square work above described, the retreating method is practised. The panels are subdivided by cross-roads and headings into pillars, which are worked off on a short face. This operation may be effected in either one or two operations, according to the section of the seam and other local conditions, if, in one operation, care is always taken to pack the goaf systematically and efficiently.

* N.B.—It was not given in evidence, but a method is now being practised at Baggeridge Colliery which is said to result in almost complete extraction of the coal. It is described in the Transactions of the Institution of Mining Engineers, Vol. LVIII., Part 4, April 1920.

In either case, because of the abnormal thickness, but, especially in Square work, considerable crushing of the ribs and pillars and consequent breakage of the coal takes place, so that accumulations of small coal, slack, and dirt on the floor are unavoidable (*Q.* 11,943). It was the general experience of witnesses that the firing of the coal is infrequent in the case of single roads, and that pillars 30 or 40 yards square are safe so long as they remain unbroken. This is largely a question of the depth of the seam from the surface, *e.g.*, at a depth of 500 yards the roads should not be closer together than 50 yards with cross-cuts or thirlings at least 100 yards apart. It is when the pillar becomes cracked and fissured through weight that the danger arises, on account of the passage of air through the fissures and the deposit of sooty coal which is invariably found within these cracks.

Timber.—Systematic timbering of the Thick Coal is well nigh impossible, and it would appear that quantities of timber are unavoidably left behind. *Mr. Meachem* did not think that the timber which was left in was a primary source of fire (*Q.* 3089), but *Mr. Holland* was of opinion that goaf timber is a frequent cause of fire, not so much on account of the possibility of the timber catching fire, but rather because of its forming a cavity round which air might circulate (*Q.* 7821).

(C) *Preventive Measures.*

(i) *The Methods in operation for Preventing Gob-fires.*

In the Thick Coal workings of South Staffordshire certain precautions are taken to prevent the outbreak of fires and to localise their effect, and notable among these is the method of working adopted. In the panel system, dams can be built in such a manner as to isolate quickly any one district, and provision should be made at certain points for sealing off districts. If fires are frequent water pipes should be laid along the main roads and a supply of water should always be immediately available. One of the essentials in working out these panels is speed, and to attain this end double shifts have been introduced at Hamstead Colliery. It was stated that in three months after the opening of a panel fires almost invariably broke out (*Q.* 7823). *Mr. Meachem* said: "The whole of the slack must come out" and "under no circumstances do we allow "slack to remain behind." He also advocated having as great a volume of ventilation as possible "to keep down the heat and take it away." Blasting with explosives is reduced to a minimum on the ground that it breaks the coal into fine dust (*Q.* 2921). He considered that a pillar should never be left in any circumstances, that all timber should be drawn, and that all main roads should be driven to the boundary or to the boundary of a panel, leaving a rib all round such panel and the coal "worked home," damming off at regular intervals (*Q.* 3224).

(ii) *The Methods in operation for Dealing with Gob-fires when they occur.*

Where heating occurs in a panel of Thick Coal, the first intimation is a rise of temperature in the panel accompanied by black damp. Sweating occurs, followed by fire-stink. *Mr. Holland* declared that such fires were seldom got at and dug out, because the roof was generally too broken down behind the workings to allow of it being done. "Sometimes water is pumped in by hand pumps to keep the fire down "until the remaining coal is cleared out of the panel, when the panel is sealed off by "sand dams. These sand dams are built in the roads at the entrance to the panel "and are supported by dirt dams at the back and by rocks and bricks and timber in "front." On the question of water, however, he was of the opinion that the use of small quantities usually drives the fire to another part of the opening (*Q.* 7964). *Mr. Meachem* informed us that it was his practice, on discovery even of sweating in a stall, at once to dam off the stall, reduce the oxygen within the stall by exclusion of air and leave the place for one month (*Q.* 2921–2933). He made no attempt to load out any fire occurring in the goaves or stalls.

Fires in solid coal constituting the sides of the main roads are common and are regarded as being more serious than those in the goaf. Strict watch is kept on all likely places and at the first sign of heating a road is driven into the coal and the heated material loaded out (*Q.* 3060, 7860 and 12,015). Fig. 28 shows a cross section in the Thick Coal and the nature and position of the "breaks" due to pressure.

Note.—Drive small heads wherever break occurs.

Stage 1. Breaks produced by pressure.
2. Fine dust fills breaks.
3. Absorption of oxygen and process of distillation begins.
4. Heat generated. Admission of air.
5. Ignition.

FIG. 28. CROSS SECTION OF COAL ROAD IN THE THICK COAL, SHOWING NATURE AND POSITION OF "BREAKS" DUE TO PRESSURE.

Messrs. Meachem and Holland also emphasised the importance of at once dealing with road-fires owing to the rapidity with which they spread. The former advocated the liberal use of water pipes along main roads, the removal of all wood cogs, or covering these with cast-iron plates to render them innocuous, the provision of cast-iron doors, and finally the driving of all main roads not in the Thick Coal but in the Whitestone measures some 19 yards below it. Fig. 29 is reduced from a plan put in by Mr. Meachem to illustrate his proposal.

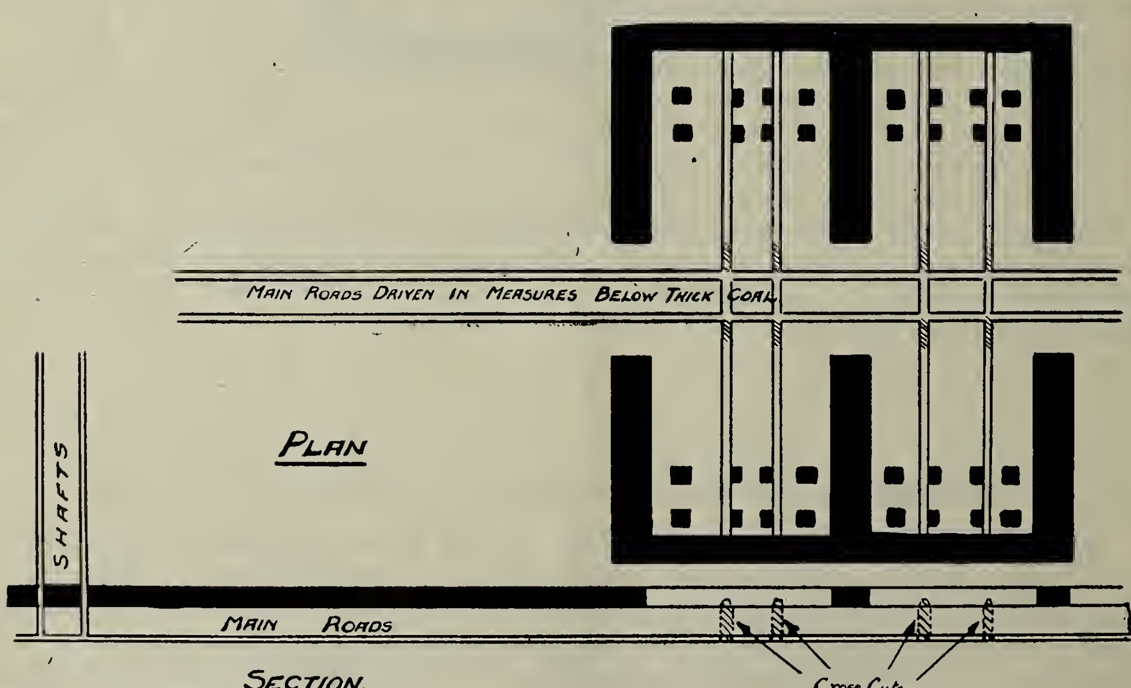


FIG. 29. PROPOSED METHOD OF OPENING A THICK COAL PIT WHERE THE SEAM IS MORE THAN 20 FEET THICK AND OVER 400 YARDS IN DEPTH FROM THE SURFACE.

Figs. 30 and 30A are plan and section of a type of dam used by Mr. Meachem in a main road in the Thick Coal. The section gives details of the dam, which consists of a dirt "vie," a sand dam and brick retaining walls. One such dam was constructed,

and after two or three years it was found necessary to re-case it, owing to the continual heating and breaking of the coal on the sides (*Q.* 3057).

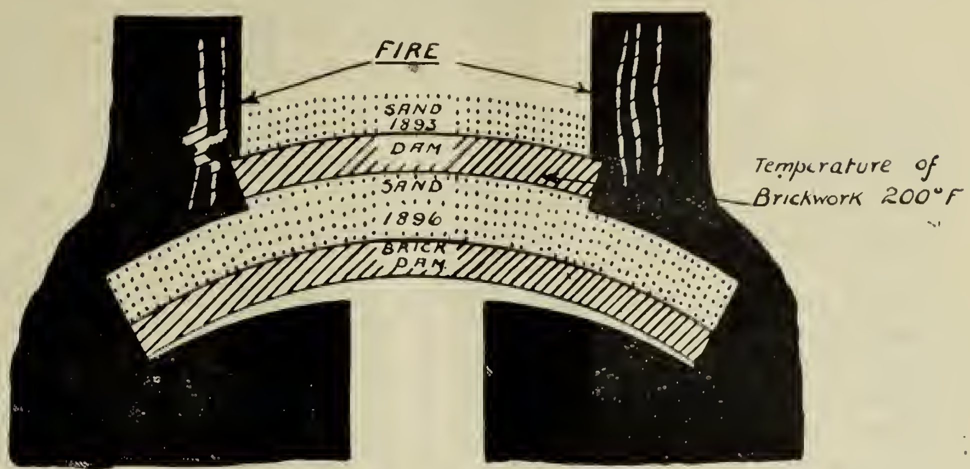


FIG. 30. DAM IN A MAIN ROAD.

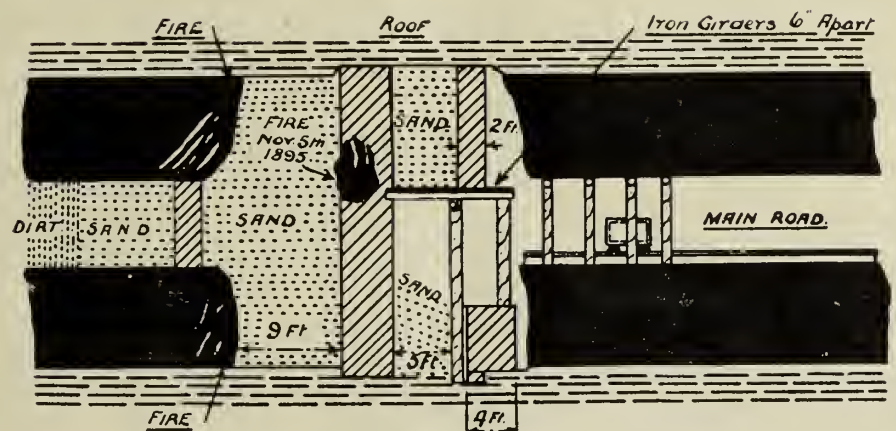


FIG. 30A. SECTION OF DAM. SHOWING METHOD OF RE-CASING.

THE AREA NORTH OF THE GREAT BENTLEY FAULT.

(A) *Geological Conditions.*

From the point of view of liability to spontaneous combustion the district north of the Great Bentley Fault is more favoured geologically than the area to the south, and because of the better conditions it has been possible to lay out the workings of the collieries in a more systematic manner. The seams are more normal in thickness and in only a few is there any great tendency to spontaneous combustion in the goaf. One of these is the Shallow Seam, which is about 9 feet thick. The roof is composed of black shale or " bass," 3 to 4 feet thick, and above this is a white bind or rock. The top section of the Shallow Coal, called " Brights," contains bands of iron pyrites, and it is stated that it is this top portion which is most liable to fire spontaneously. In close proximity to the Shallow Seam is the Deep Coal which occurs from 1 foot to 20 yards below the former.

Associated with these seams is a carbonaceous shale which in the opinion of witnesses is directly contributory to the fires (*Q.* 8766 and 12,160).

Another seam—the Six-foot Coal, about 4 ft. 6 ins. thick—is also reputed to be liable to spontaneous combustion, and of it *Colonel R. S. Williamson* (Managing Director of the Cannock and Rugeley Collieries) said : " We have had fires in that " seam where we were extracting the pillars with a sandstone rock roof " (*Q.* 10,217).

A third seam which is subject to self-heating is the Seven-feet Seam near Aldridge, which *Mr. T. H. Bailey* described as being on the same geological horizon as the upper beds of the South Staffordshire Thick Coal. This coal seam contains bands of black carbonaceous shale which in former days was invariably thrown into the waste or placed in the packs, and which in his opinion was the cause of the fires (*Q.* 12,156).

Shallow Coal, Cannock and Rugeley Collieries.

(*Q.* 10,151.)

	Ft. ins.	Ft. ins.
Roof : Bass or Dark Shale	—	2 10
QUECELET	1 0	—
Parting	—	—
HARD COAL	1 0	—
Parting	—	—
BRIGHT COAL	1 0	—
Parting	—	—
GOOD COAL	0 7	—
Parting	—	—
BROWN HARD COAL	0 3	—
Parting	—	—
MAIN COAL	3 5	—
Parting	—	—
SLOTTING COAL	2 5	—
Black Bat or Pricking	—	0 7
Fireclay	—	0 10
Total Thickness	9 8	1 5

Shallow Coal, West Cannock.

	Ft. in.	Ft. in.	Ft. in.
Shallow rock	—	—	—
Bass	—	3 6	3 6
QUESLETS. (Timbered to underside in roads and wastes); Parting; HARDS; BRIGHTS. (Timbered to underside in face)	2 6	—	—
Parting	—	—	—
BROWN ONES	0 9	—	—
Parting	—	—	—
MIDDLES	1 6	—	—
Smooth shale (Bannock in this dirt)	—	0 1½ to	0 4
BOTTOMS (floor)	4 3	—	—
Black Bat (in floor)	—	1 0 to	2 0
Rock	—	—	—
Total Thickness	9 0	4 7½ to	5 10

Seven Feet Coal, Aldridge Colliery.

	Ft. in.	Ft. in.	Ft. in.
White Rock Binds	—	—	—
ROOF COAL	1 0	—	—
Black Carbonaceous Dirt	—	0 5 to	1 0
COAL	0 10	—	—
Black Carbonaceous Dirt and Batt	—	0 8 to	1 2
COAL (sometimes with 4 dirt partings in middle)	1 8	—	—
Stoney Band "Brown George"	—	—	0 4
COAL	1 7	—	—
Parting	—	—	—
INFERIOR COAL, "WATER PEEL"	0 6	—	—
Fireclay	—	—	—
Total Thickness	5 7	1 1 to	2 6

Questioned as to the pyrites in the coal, Colonel Williamson described it as being sometimes disseminated throughout the coal in streaks and as sometimes occurring in the form of nodules. The "Brights" was described as being a good bright coal, but not so hard as the bottom section. He was of opinion that the pyrites has some bearing on the question of spontaneous combustion (*Q.* 10,284).

Colonel Williamson's evidence as to the occurrence of fires in the Six-foot Coal (which averages 4 ft. 6 in. thick) is of interest, inasmuch as it is one of the very few cases where a thin seam with sandstone roof was described as liable to spontaneous combustion. It must, however, be noted that the fires were due to the coal being crushed where the pillars were being got out, and to air pulling through the crushed coal (*Q.* 10,225).

Although the coalfield as a whole is not so badly cut up by large faults and other geological disturbances as is the case further south, yet there are many smaller faults throughout the field which interfere with the workings, inasmuch as they control the length of working face. *Mr. J. C. Forrest*, Managing Director of the Holly Bank Colliery, stated that he invariably tried to pack the sides of faults to prevent leakage of air thereon, and he was satisfied that fires occurred along fault sides where the packing was indifferent (*Q.* 8825). Colonel Williamson said: "Faults, slips, and "breaks in the roof are attributable for causing 'cavities' or openings through which "the air can pull and feed any heating that may be taking place in the goaf."

Mr. J. Smithurst, Agent and Manager of the West Cannock Collieries, said: "In my experience I have found a number of fires in the neighbourhood of faults, and "I have very often found they have left coal along the side of the faults which has "been inferior. Sometimes they have not properly sealed the road up leading to the "fault, and we have had a fire alongside the fault side."

It was pointed out to us that the coals in this locality were extremely high in moisture content (*Q.* 10,151), and that the higher the moisture the greater the proneness to spontaneous combustion. This was stated by Colonel Williamson to be general throughout the Cannock Chase district (*Q.* 12,247 and *see* page 16).

(B) *Mining Conditions.*

Methods of Working.—The longwall method of working is almost universally adopted in the South Staffordshire coalfield north of the Great Bentley Fault, the system being modified to meet local conditions. For example, at Holly Bank Colliery, where the Shallow and the Deep Seams come close together, it is the custom to carry the workings in the Deep Seam 10 yards in front of the Shallow (*Q.* 8772).

At West Cannock Collieries, also working the Shallow Seam, a portion of the seam is taken as a first working, leaving 3 feet or so of the tops as a roof. The packs are built up to the tops, more than half of which is ultimately got in the waste and roads (*Q.* 11,646). The loss of coal is so serious that Mr. Smithurst said he was considering the possibility of recovering the tops by means of a second working.

Colonel Williamson observed that it had been his experience that better all-round results were obtained by first working the Deep coal and allowing sufficient time for settlement before getting the Shallow seam, which at Cannock and Rugeley Collieries is 20 yards above the Deep. Here also the system in operation is longwall, the coal, in the majority of cases, being headed out in the solid by either two or three roads, and the working places started off from the "counter" or rib road (*Q.* 10,166). (Figs. 31 and 32.)

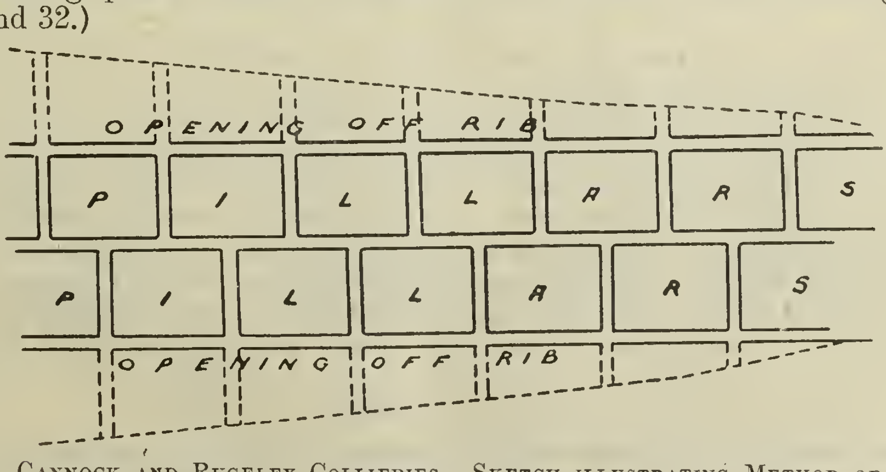


Fig. 31. Cannock and Rugeley Collieries. Sketch illustrating Method of Opening out Longwall (*Q.* 10,166).

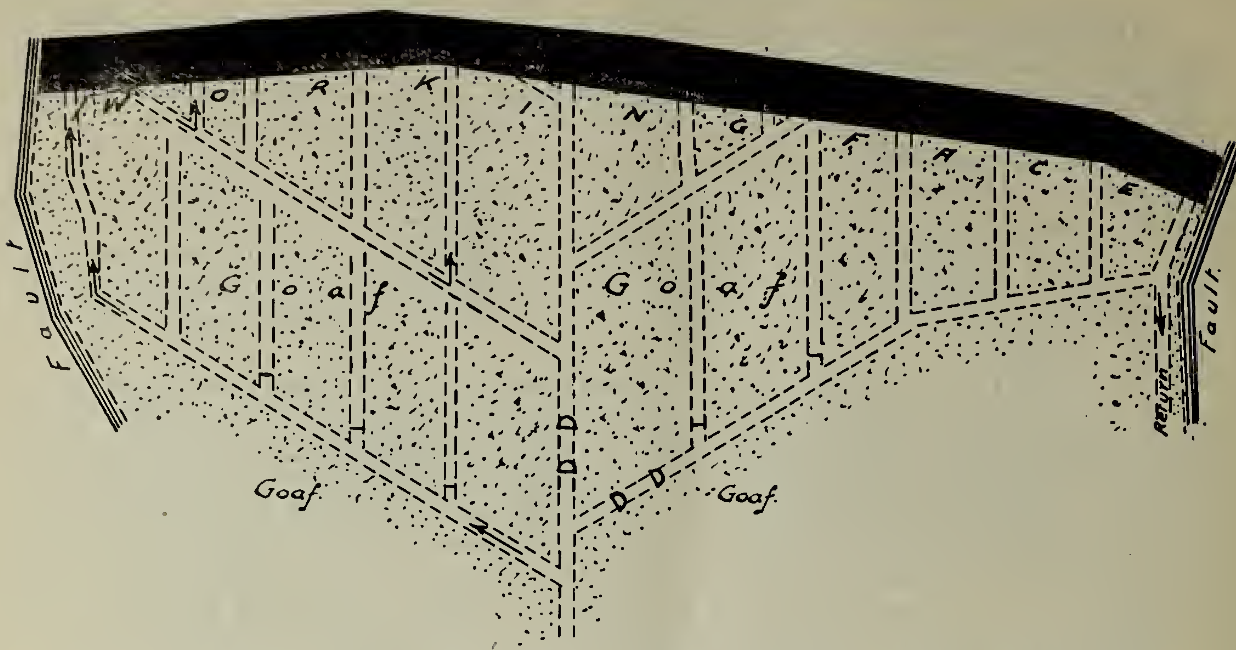


FIG. 32. CANNOCK AND RUGELEY COLLIERIES. LONGWALL METHOD OF WORKING (Q. 10,158).

Mr. Bailey laid down certain general principles relating to the adoption of the longwall method of working. He said :—

i. As few pillars should be left as possible.
ii. The workings should be advanced as systematically as possible.
iii. The aim should be to rip the roads and bury the goaf as quickly as possible. If, owing to roof conditions, there are difficulties in effectually carrying out this latter, the leakage of air through the goaf and access of air to combustible material unavoidably left therein should be prevented.
iv. Timber should be systematically withdrawn so as to ensure that none is left in inaccessible parts of the mine.
v. Falls of coal or roof should not be left, but should be removed as soon after the occurrence as possible (*Q.* 12,352).

COAL LEFT IN WASTES.—As has been stated, part of the coal in seams in this district is sometimes left up to form the immediate roof, which, although partly recovered in the waste and in the gate roads, often falls too far back in the waste for recovery. Frequently, too, the holing is done in the coal itself, and a considerable quantity of very fine slack is the result, a proportion of which may be left or thrown behind in the waste. Colonel Williamson considered that the complete removal of the slack and coal is one of the most important precautions to be taken (*Q.* 10,301). *Mr. Smithurst* declared he had had fires and heatings in the waste where top coal had broken down and become crushed (*Q.* 11,650), and that he had made a rule that the casting back of small coal into the waste should cease (*Q.* 12,134). *Mr. J. Owen*, an overman from the West Cannock district said: "If you meet with a piece of coal, " I do not care what size it is, and it is inferior—they leave it behind sometimes " and it makes a lot of slack. There is a grind on that, a pressure, and it is best " filled out."

CRUSHING OF PILLARS.—As the method of working is chiefly longwall, the question of the occurrence of fires in crushed pillars is not so pronounced, but the concensus of opinion was that the leaving of small pillars was reprehensible. It was argued that in longwall workings, as soon as the shaft pillar was completed, all coal should be completely removed, and the main roads packed and maintained through the wastes. Examples were given of fires occurring in shaft pillars, and it was suggested that as few roads as possible should be cut through them. As for ordinary pillars, Mr. Smithurst expressed the fear that no matter what size these were, there was danger of fire occurring along the rib sides. *Mr. Forrest* was insistent on the desirability of leaving very large shaft pillars and keeping roads driven in the solid as far apart as possible (*Q.* 8944–53). He prevented fires on the rib sides of pillars by packing efficiently with dirt brought from the surface.

PACKS.—Sufficient evidence was forthcoming to convince us that the importance of building good packs along the gate roads in mines liable to spontaneous combustion

was fully realised. Where sufficient material of a suitable character is not available in a seam subject to heating it would appear to be customary to bring such material from other seams, or even from the surface (*Q.* 8772 and 12,156). Without exception, witnesses expressed the view that roadside packs in longwall workings should be wide and built as solidly as possible with incombustible material, the width of packs mentioned ranging from 5 yards to 8 yards (*Q.* 8807, 10,339, 11,647, 12,141, 12,156, and 6834). Several of the witnesses were firmly convinced that success in working and freedom from fires only followed the abandonment of narrow packs and the introduction along gate roads of packs 6 to 8 yards wide.

We were much surprised to find that Mr. Bailey did not attach much importance to the exclusion of coal from packs, and he stated, in contradistinction to most other witnesses, that he had never known of trouble arising from such a procedure (*Q.* 12,142-4). On the question of centre or "cross packs," witnesses were not unanimous, but the weight of the evidence made it clear that the local practice was to insert packs between the gate-roads and parallel to them varying in number and thickness according to the distance between stalls. Mr. Bailey did not advise the use of centre packs, pinning his faith on wide road packs (*Q.* 12,136), but Mr. Forrest, on the other hand, could not recommend 10-yard wide packs alongside gate-roads, with the exclusion of centre packs, on the ground that with no centre packs the tendency was to leave the timber in the face (*Q.* 8940). No evidence was forthcoming as to fires occurring over packs as a consequence of top coal being left on. Several witnesses strongly recommended that the goaf should be frequently cut off by cross-gates, which latter should be thoroughly packed to prevent leakage.

The following sketches are reproduced from plans produced in evidence by Colonel Williamson, and are illustrative of the methods of working and packing adopted by him at the Cannock and Rugeley Collieries.

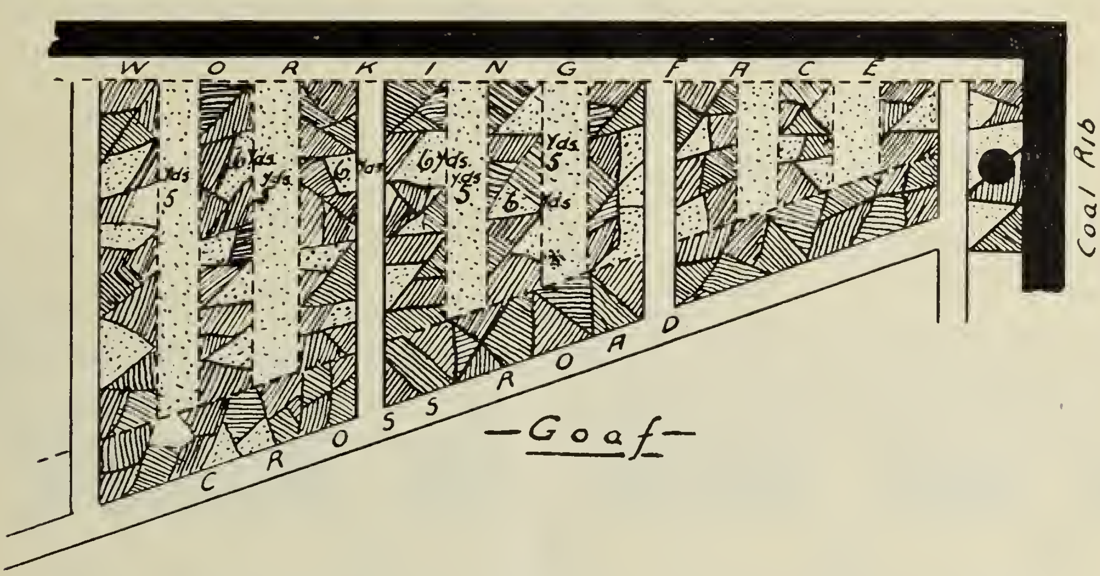


Fig. 33. Cannock and Rugeley Collieries. Plan showing Packs and Wastes.

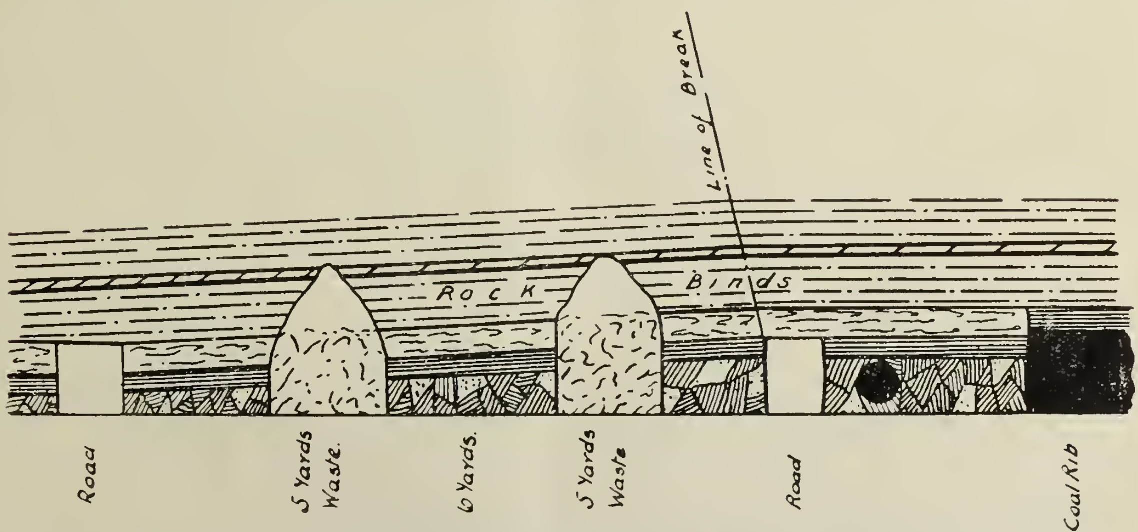


Fig. 33a. Cannock and Rugeley Collieries. Section showing Line of Break, and probable Position of Fire.

(*Site of fire indicated by black circle.*)

Figs. 33 and 33A were put in by Colonel Williamson as showing how the fracture usually occurs. He indicated that the majority of the fires occurred between the road and the rib-side (Q. 10,155). Figs. 34 and 34A are of a similar section where, instead of a rib-side, there is a fault (Q. 10,158).

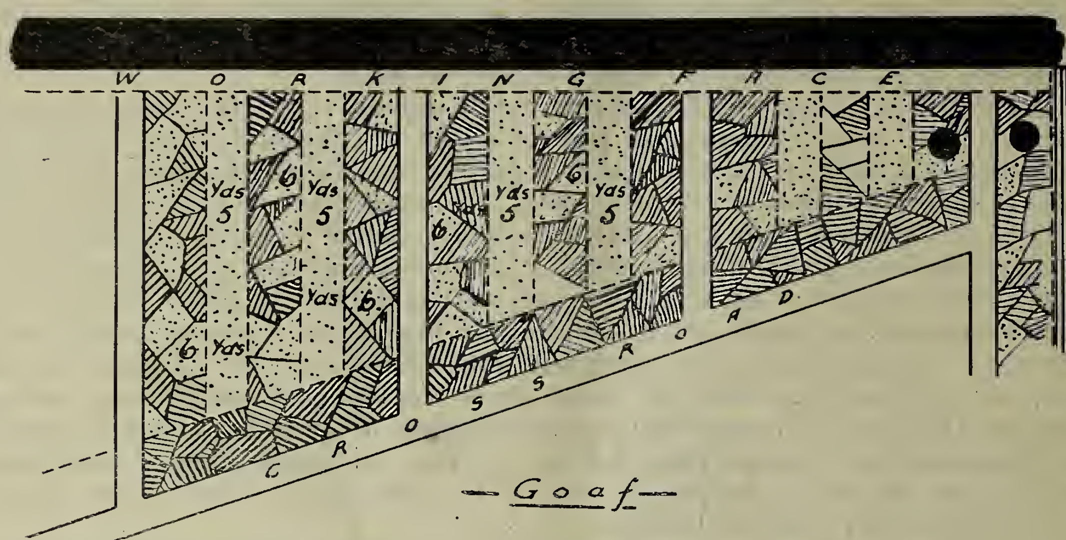


FIG. 34. CANNOCK AND RUGELEY COLLIERIES. PLAN SHOWING PACKS AND WASTES.

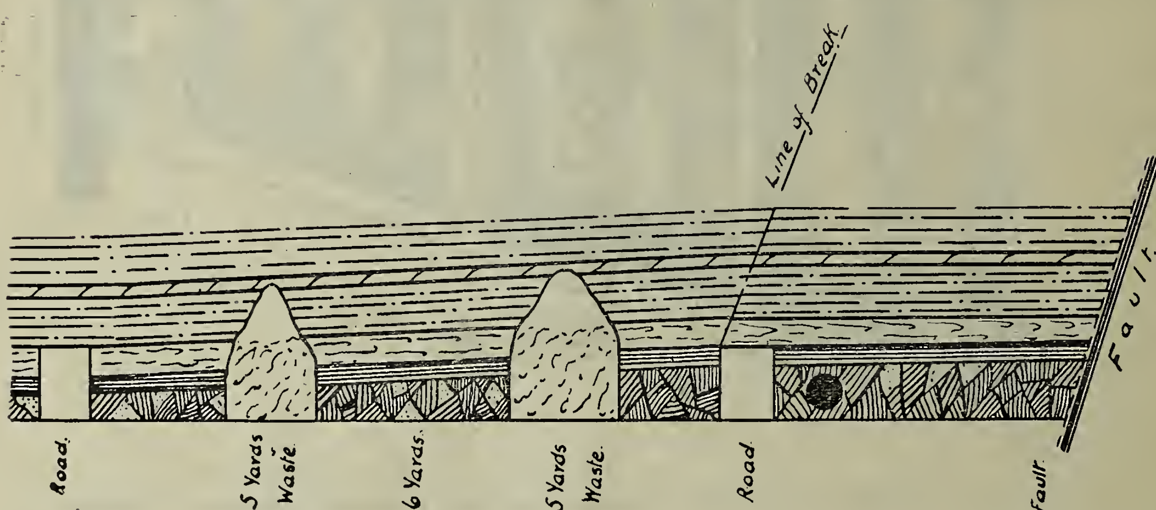


FIG 34A. CANNOCK AND RUGELEY COLLIERIES. SECTION SHOWING LINE OF BREAK AND PROBABLE POSITION OF FIRE.

(Site of fire indicated by black circle.)

LEAKAGE OF AIR ACROSS GATEWAYS, THROUGH PACKS OR WASTES.—The majority of the witnesses agreed that the uncontrolled leakage of air through packs to the waste was a most undesirable state of affairs. For example, Mr. Forrest said that frequently heating occurs in wastes as a direct result of putting extra air pressure on to roads before the road packs have had time to consolidate (Q. 8814). Colonel Williamson said that "if the ventilation is good and somewhat concentrated, and the 'cogging' "and buildings not made up solid, the air pulls through and there is greater "liability for the gob to heat, which invariably leads to fires. . . . . . Too "much air is not always desirable." It is often noticed that "doors, stoppings and "brattice are wrongly placed so that air is driven across from road to road instead "of round the face" (Q. 8814).

Mr. Forrest remarked that the general rule is that where breaks are found crossing the coal, due to the character of the roof or the coal itself, air may penetrate the breaks, and, being retarded, set up undue pressure on the gob, causing fire therein (*Q.* 8814). The same thing was said of falls on the face or in gate-roads. It was generally believed to be good practice to exclude all air from the goaves.

Timber left in Wastes.—There was no dissentient among the witnesses to our suggestion that timber should invariably be withdrawn, although there was some dubiety as to the part played by timber in the propagation of underground fires. The general opinion was that upright props acted as a sort of chimney allowing a free access of air from the floor to the roof where top coal might have been left. Mr. Forrest was of the opinion that when the "weight" came on the top coal, grinding took place on the top of any props inadvertently left standing; the resultant slack fell to the foot of the props and heating took place. As to whether the prop or the slack would fire first, he was unable to say definitely as he had found cases of each (*Q.* 8856). Colonel Williamson was asked if he could point to instances where gob-fires had been directly traceable to timber being left in the goaf, and replied in the affirmative; he said: "One of the worst fires I have ever "had to deal with in our Deep Seam—which is not a seam liable to spontaneous com- "bustion—was entirely attributable to back timber being left in . . . . When we "got into this goaf . . . . we found the timber all charred. It was simply the "fact of the timber having been left there, and the slack in the vicinity of those "trees that caused that gob-heating." He recommended that all timber should be withdrawn, no matter whether it was in the form of props or lids (*Q.* 10,422). Witnesses were in general agreement that quite apart from timber being directly connected with gob-fires, it was so indirectly, inasmuch as standing timber in the goaf prevents an even and rapid settlement of the roof, thus making conditions in the goaf suitable for the starting and propagation of fires.

(C) *Preventive Measures.*

(i) *The Methods in operation for Preventing Gob-fires.*

Those methods actually in operation have already been touched on (at least by inference) in the previous pages when we were considering the causes of spontaneous combustion, but several witnesses gave details of what was done at individual collieries. These may be summarised as follows:—

Colonel Williamson:—

i. Holing always done in under dirt and not in the coal.
ii. Rule in force whereby workmen are required to send daily out of each place a certain proportion of slack to coal.
iii. All back timber withdrawn as far as possible.
iv. Wastes built off at regular intervals.
v. Stoppings placed in all disused roads.
vi. Flue dust on all main roads.

Mr. Smithurst:—

i. Fan kept at a constant speed.
ii. All slack and inferior coal filled out and sent to the surface.
iii. All timber withdrawn as far as practicable.
iv. Gate roads lifted above the level of the top of the packs, and the fireclay bottom, where possible, lifted and built into the packs.
v. Great care exercised in the fixing of doors and brattice cloths.
vi. Extraction of all pillars of coal.

Mr. Bailey:—

i. Regular line of face.
ii. Removal of all coal from faults and efficient packing of faults.
iii. Prevention of leakage of air through breaks or packs into the goaf.

Mr. Bailey and Mr. Forrest also gave details which are covered above, and the latter told us that he had a specially trained body of underground workmen—termed a fire-gang—in each working shift, whose duty it was to investigate immediately any reported fire-stink and thereafter take such action as might be necessary.

(ii) *The Methods in operation for Dealing with Gob-fires when they Occur.*

In South Staffordshire, as elsewhere, the first indication of a gob-fire is generally found to be "sweating" or moisture due in all probability to condensation rising from the heating of the coal. There may or may not be a steamy or foggy atmosphere accompanying the sweating, but, in Mr. Smithurst's opinion, the fog will be absent in a warm atmosphere (*Q.* 11,707). Succeeding the sweating are the odours of combustion, described variously as "paraffin" or "benzoline," "like a snuffed-out paraffin lamp," as sometimes sour and sometimes sweet—depending on whether or not timber is present.

As soon as the first symptoms are apparent, immediate action is taken either by the specially trained gang previously mentioned, or by the overman and his deputies. A search is made to find out the point where the heat, sweating, steam, or smell is issuing from, and whichever sign is found it is traced along the point or line of issue until the heated material is located; then, if practicable, a road is made to the heated material, the whole of which is filled out. Sometimes a second road is made, and if there is good cool ventilation it is carefully turned into the place until the latter has been properly cooled down (*Q.* 11,723). It was pointed out to us though, even by the strongest apostles of "loading out," that this can only be done with safety in the absence of gas, with a good roof and where there is easy access to the site of the fire. For example, Colonel Williamson said, "If the fire can be localised (and circumstances "permit) and readily got at, and it is not too large, we cool it down by admitting a "certain amount of air, or with water or fire extinguishers, and load it into tubs and "send it out of the pit. If, however, the heated area of the fire has a bad roof, is "likely to give off gas, is not very accessible, and suitable stoppings can be put on "to exclude the air from it, and it can be properly built off, this is done." With regard to the use of water for extinguishing the fires, Mr. Forrest held the theory that its effect is bad, as apart from steam obscuring the men's vision and injuring the roof, he declared that the water becomes hot, runs off to the dip, and propagates other fires in its course. He was so convinced of this that he no longer allows water to be turned on to the site of a fire (*Q.* 8779). Mr. Smithurst was in complete agreement with this view (*Q.* 11,696), as was Mr. Bailey also (*Q.* 12,123). Mr. Forrest uses sand in large quantities instead of water, and is satisfied with its efficacy. He strongly advocated the use of a sand blast worked by compressed air in roads where timber was on fire, urging that it would be more effective than water as an extinguisher, and that it would do no damage to roof, floor and sides (*Q.* 8851).

Witnesses in general thought it advisable to reduce the air pressure as much as possible in the vicinity of a fire. When the fire is such that loading-out cannot successfully be undertaken, preparations are at once commenced to dam-off the district, taking the precaution of placing the stoppings as near the outbreak as possible. The methods adopted vary greatly, and are dependent on the attendant circumstances of each case, but the principles are the same, namely, the complete isolation of the fire as quickly as possible, and not leaving the work until the position has been made secure. Sometimes long lengths of roadway are stowed tight with sand or flue dust between two stoppings of brickwork, and Mr. Smithurst stated that occasionally he cut a new road completely round a fire, stowing it with the flue dust or sand. Mr. Forrest described a case to us where he had successfully dealt with a fire by bringing black damp on to it. He advocated loading-out wherever possible, but, where this is impossible, he said that fires were dealt with "by taking the ventilation off and putting "sand packs at the required points in the gob, when the latter is found solid and firm ". . . . . . . My experience is, if you are careful how you dam, you can dam "anywhere; but that is, if you are careful not to pack too close to your face. ". . . . . . . The gas, consisting of methane and carbon dioxide, comes down "and stifles the fire."

3. WARWICKSHIRE.

The seam known as the Warwickshire Thick Coal, having an average thickness of 23 feet, is formed by the thinning out of various interstratified beds of sandstone and shales which separate several of the seams of coal in the northern part of the field, and occupies a considerable area towards the southern portion of the county. At Wyken and north of Bedworth the shale beds intervene and the seams assume a more or less normal condition. Towards the west and south-west, so far as geological investigation has proved the field, the coal exists in its thick state and is probably an extension of the Staffordshire Coal-field as occurring at Hamstead and Sandwell Park; and it may be that a continuous field exists between Coventry and Hamstead.

(A) *Geological Conditions.*

The sections of the Thick Coal shown below were put in as evidence by *Mr. C. F. Jackson*, Agent and Manager of the Exhall Colliery and Agent of the Newdigate Colliery, and by *Mr. J. T. Browne* (formerly General Manager at Newdigate), who also gave the following description of the various seams. The roof of the Two Yard Seam is a shaly bind generally containing ironstone both nodular and in irregular layers. It is of an exceedingly friable and variable character at Newdigate, and liable to falls of considerable height. The Bare Coal is rather soft and often contains thin layers of "dant." It has rarely been worked north of Bedworth. The Ryder Coal to the north of Bedworth, near the outcrop (where it is seldom worked), is an inferior coal, but at Newdigate in the deeper workings a considerable portion of the seam is hard and bright. It is subject, however, to the occurrence of bands of pyrites, and near the top occurs a well defined band of stone from 1 to 3 inches thick known as the Ryder stone, which is a general characteristic of the seam throughout the district. The Ell Coal is sometimes separated from the Ryder by a few inches of shale, but more often by a mere parting of "dant." The upper portion is somewhat soft, but the Spires is a valuable high-class steam coal also used in annealing and for similar purposes. The Slate Coal (sometimes described when combined with the Ell Coal as the Nine Foot) forms the lowest division of the Thick Coal Seam, and generally an inch or two of "lam" (a slippery shale) occurs at the top of the seam. The floor is usually a strong fireclay. About 18 inches from the top of the Slate Coal is a band of a black coaly substance known as the "bat," 1 to 2 inches thick and containing 50 per cent. of ash (*Q.* 9794). At Newdigate Colliery, over a large area, the roof of the Two Yard Seam has been found contorted in an extraordinary manner; the coal has been squeezed and doubled over, following no regular line of rise or dip, and is, in some parts, squeezed out altogether (*Q.* 9794).

Section of Thick Coal at Exhall Colliery.

(*Q.* 9301.)

	Ft. ins.	Ft. ins.
Roof:—A weak and friable Bind:		
TWO YARD COAL - - - - -	4 9	—
Lam - - - - - - -	—	0 6
BARE COAL - - - - - -	1 1	—
Ryder Stone - - - - - -	—	0 11
RYDER COAL - - - - - -	4 6	—
ELL COAL - - - - - -	4 3	—
BLACK COAL - - - - - -	0 8	—
Lam (8 ins. to 24 ins. thick) - - -	—	0 8
"3/4" COAL - - - - - -	1 3	—
Bat - - - - - - -	—	0 2
SLATE COAL - - - - - -	4 7	—
Floor:—Fireclay.		
Total Thickness - -	21 1	2 3

Detailed Section of Thick Coal at Newdigate Colliery (*Q.* 9794).

		Ft. ins.	Ft. ins.	Ft. ins.
Roof :—Shale.				
Black Bass		—		0 2
Two Yard Coal	Bright Soft	0 4		—
	Spires	0 6		—
	Bright	0 6		—
	Spires	0 9		—
	Bright	2 3		—
	Bright Soft	1 8	6 0	—
Fireclay		—		0 4
Bare Coal	Soft (with "dant" partings)	2 3		—
	Pyrites	—	2 3	0 1
Ryder Coal	Spires	0 5		—
	Pyrites	—		0 3
	Bright (with pyrites)	1 4		—
	Spires	2 0		—
	Bottom Bright (with pyrites)	2 0	5 9	—
"Dant" parting		—		—
Ell Coal	Black Coal	2 1		—
	Spires	0 9	2 10	—
"Lam" (a slippery shale)		—		0 2
Slate Coal	Tops	1 6		—
	Bat	—		0 1
	Brights	2 4		—
	Bottom	2 7	6 5	—
Floor : Clunch (strong fireclay).				
	Total Thickness	23 3	23 3	1 1

Gross Thickness, roof to floor, 24 ft. 4 ins.

The Thick Coal of Warwickshire has for long been characterised by its liability to spontaneous combustion, but certain parts of the seam are more liable than others, though witnesses differed in their views on this point. Thus, Mr. Jackson said : " All " the seams are, under certain conditions, liable to take fire spontaneously, and the " most liable are the two inferior coals, the Bare and the Black Coals. They are friable, " and evidently possess to a greater degree the property of more rapid oxidation than " the other coals " (*Q.* 9311). Mr. Browne said : " I am not able to offer any definite " opinion with regard to the other parts of the seam, as the Two Yard is obviously " the only one which can be worked singly, but I do not believe the Slate and Ell " Seams would be liable to spontaneous combustion in working if they possessed a " roof other than the Ryder Coal which, in my opinon, is the source of all the troubles " at this colliery." He said further : " With regard to gob-fires, in working the Two " Yard singly, gob-fires are unknown at Newdigate Colliery, and it is my opinion, " founded on close observations over a number of years, that the Slate and Ell Coals " do not spontaneously ignite. The seams lying in between are, however, suspect " (*Q.* 9794). *Mr. Bailey* thought both the Slate and Ell Coals were liable to spontaneous combustion. He said : " The Warwickshire Thick Coal is known to be liable to " spontaneous combustion, but this is not strictly true of the whole seam. The middle " part of the Ell Coal, 8 inches or so in thickness, is of a very friable nature, very " readily breaking up even in the face, a large percentage falling into a fine powder. " If an Ell Coal face stands for any length of time the coal on the face will heat, as " much as 104° F. having been measured. The Slate Coal is prone to vertical " fracture. These vertical fractures are filled with the débris from the fractured coal " above, that is, powdered, and small Ell Coal ' powder,' and very probably from the " 3 inches of ' batt ' or ' oil shale ' between the Slate Coal and the Three-quarter Coal."

Immediately above the weak " binds " overlying the Two Yard Coal there is a sandstone rock, and in some cases over a small area the " binds " are missing and

the rock comes down directly on to the coal. The suggestion was made that this might explain its complete immunity from fire, but Mr. Browne considered that, as the Two Yard Coal in the southern end of the coalfield was not liable to spontaneous combustion under any conditions, this explanation could not be accepted, especially as the sandstone rock descended on to the coal in small local areas only (*Q.* 10,020 *et seq.*). The floor of the Thick Coal is usually a strong fireclay and that of the other seams throughout the field also of fireclay or "clunch."

The nature and quality of the Thick Coal varies greatly, but taken as a whole it is of excellent quality and with the exception of the Bare Coal and "Black" Coal (both of which are friable) and of the Ryder Coal (which is of inferior quality and associated with bands of pyrites) it is a hard compact coal containing about 7 per cent. moisture. The Ryder Coal contains a higher percentage of moisture, Mr. Browne stating that this was due to its porosity; in this connection it should be remembered that the Ryder Coal is that which gives most trouble from self-heating. With regard to the pyrites in the Ryder Coal, Mr. Browne said: "My own "opinion is that most of its danger lies in its disintegrating effect. There is "nothing, for example, apart from the pyrites, in the composition of the Ryder "Seam to account for its liability to fire to be greater than the Slate Coal or Two-"Yard. Its oxygen content is practically the same as most of the other seams, and "its affinity for this gas should be similar." Mr. Browne also said that he had no knowledge of a coal being liable to self-heating which, owing to the absence of partings, could be regarded as free from impurities (*Q.* 9861).

Although the coalfield is comparatively free from large faults small dislocations occur, and as usual cause trouble. Mr. Browne, in speaking of working the Slate Coal at Griff Colliery, said that all the gob-fires he had known in that seam were traceable to faults and slips where soft and "mushy" coal had been present. Again, in describing the method of working at Newdigate Colliery, he said that "gob-fires are "only to be feared when, owing to faults or inattention to packing or gobbing, the "coals above the Slate Coal have broken down in the wastes, forming a cavity and "exposing a large surface of coal." Mr. Jackson, in describing one fire, said: "Subsequent investigation showed that there was a fault in the upper seams and the "hade of the fault formed a channel along which air would be driven every time the "train of tubs passed, having the effect of a bellows or blast on the broken Bare "Coal." He remarked further, "the trouble is, I take it, a fault. It is almost "impossible to take the coal out near a bad fault." Mr. Bailey held a similar opinion and produced plans illustrating his remarks. (*See* Figs. 35 and 35A.)

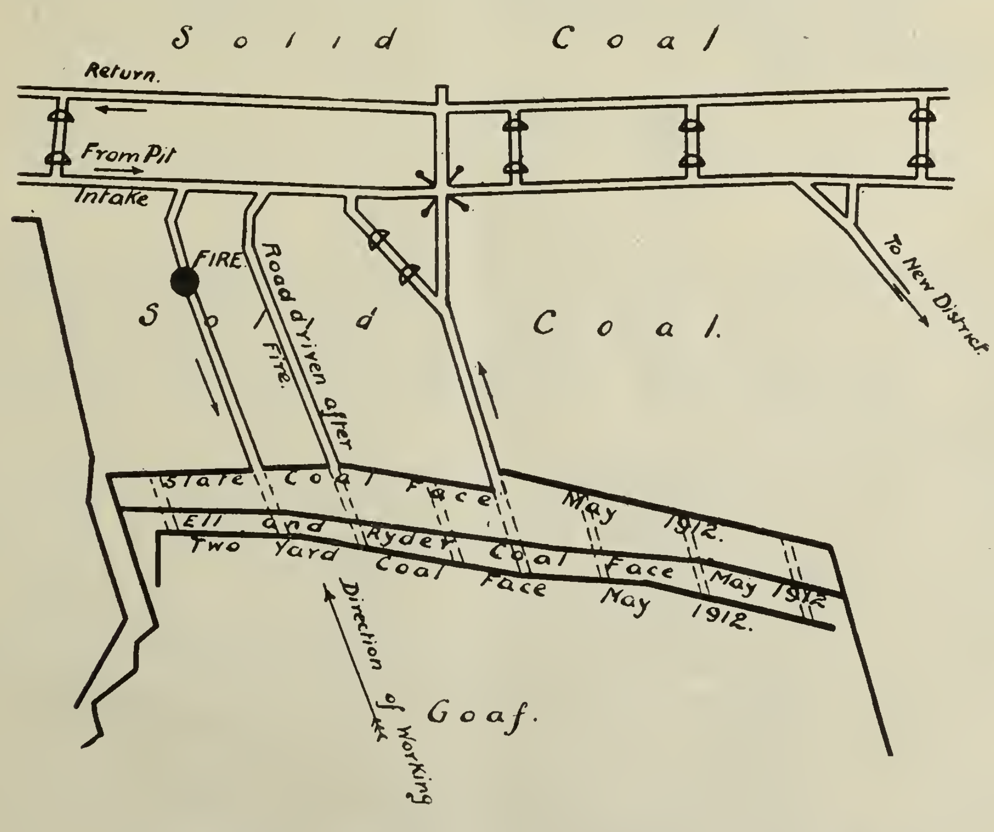


FIG. 35. EXHALL COLLIERY. SKETCH SHOWING POSITION OF FIRE.

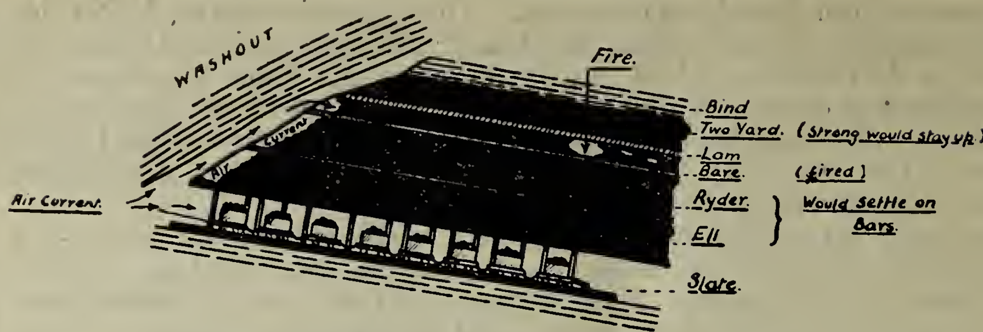


FIG. 35A. EXHALL COLLIERY. SKETCH SHOWING PROBABLE CAUSE OF FIRE.

In the northern part of the field the seams, as has been stated, assume a more normal thickness, and the trouble from spontaneous combustion is not so marked there as in the south. There are, however, two seams (the Seven-Feet and Bench Coals) which are liable to self-heating. Sections of these seams appear below, reproduced from a report to the Committee by the late *Mr. F. A. Grayston* (Mining Engineer, Amington and Glascote Collieries, Tamworth).

Amington and Glascote Collieries.—Seven-Feet Coal.

	(1) Ft. ins.	(2) Ft. ins.
Roof :—Blue Binds.		
COAL, called THIN COAL - - -	2 3	2 5
Clunch - - - - -	3 0	0 7½
Scalp - - - - - -	0 9	0 9
COAL - - - - - -	5 3	4 9
Floor :—Fireclay.		
Total Thickness - -	11 3	8 6½

Bench Coal.

	(1) Ft. ins.	(2) Ft. ins.
Roof :—Blue Binds.		
Bat or Bat and Coal mixed - - -	4 6	2 7½
COAL - - - - - -	4 6	4 3
Floor :—Clunch.		
Total Thickness - -	9 0	6 10½

(B) *Mining Conditions.*

METHODS OF WORKING.—Throughout our inquiry we endeavoured to obtain from witnesses in all districts their opinions as to the method of working most suitable to mines liable to spontaneous combustion, and made frequent allusions to the "retreating" method of Longwall. Very few of the witnesses cared to commit themselves to a definite pronouncement as to the efficacy of this method as a means of obviating trouble from fires.

This method of working is by no means common throughout the coalfields of Great Britain, but in Warwickshire it has been, and is practised with a great measure of success. The working of the Thick Coal at Exhall and Newdigate Collieries affords excellent examples of this method of exhausting a thick seam of coal by working in layers or successive faces from the boundaries towards the shafts.

It is not the invariable practice to work the Warwickshire coals by this method. For example, at Binley Colliery the Two Yard Coal is being worked first by advancing longwall, the Thick Coal being divided into seams by beds of fireclay and binds. At Kingsbury Colliery the Ryder Coal is worked by advancing longwall ; but here too the Thick Coal is split up into seams and is altered in character (*Q.* 12,084).

Again the Seven Foot Coal and the Bench Coal of the northern area are worked most frequently "longwall advancing," and in both cases a portion of the top coal is left to form the roof. The seams are worked both "end-on" and "face-on,"

according to local conditions, and the roads in the gob are ripped as early as possible to enable them to stand better and to prevent leakage of air to the goaves. Occasionally the Seven Foot Seam is worked on the retreating system.

It is obvious that in the latter method of working a considerable time must elapse before a large output is obtained, and it is customary to work such areas as lie to the rise by advancing longwall while the main roads are being driven either to a natural or to an artificial boundary.

In working the Thick Coal the main intake and return roadways are usually driven in the Slate Coal—the lowest bed of the seam. When the boundary is reached a thirling or heading is driven across from one dip to the other to form a panel, and wing roads are driven to the right and left of the two dips for 5 or 6 chains, thus forming a face of work in the Slate Coal 15 to 20 chains across. This face is then worked outbye, the holding being done in the "lam" at the top of the seam and packs built behind, dirt being sent from the surface for this purpose when necessary. The floor is not disturbed but lifts naturally and forms a most useful factor in squeezing tight the gobbing material. "In fact," said *Mr. Browne*, "it may " be said that in maintaining this condition lies the whole success or otherwise of " the system, it being most essential that the seams above shall not be broken " unduly." Having advanced the Slate Coal face a specified distance, ranging from 10 to 20 yards, "congates," "conduits," or "stall-roads" (as they are variously termed) some seven feet wide are driven to the deep, from 25 to 28 yards apart, by ripping into the Ell Coal at such an inclination that the road thus formed is partly in the Slate Coal waste and partly in the Ell Coal. As soon as these congates are in the full thickness of the Ell Coal and in from 2 to 4 feet of the Ryder Coal, roads are driven right and left until the congates are connected and a face of coal thus formed, partly in the Ell Coal and partly in the Ryder Coal. The constant lifting of the floor forces up the Slate Coal gobbing very tightly, and some of this is in turn thrown back into the Ryder waste and is augmented by imported material. The congates are continued to the deep until the Two Yard Seam is entered, and as soon as the previous face has advanced some 10 yards or so, a face is opened out in the Bare Coal and in some 4 feet of the Two Yard Coal, the remaining 18 to 20 inches of the last-named seam being left up as a roof (*see* Figs. 36 and 36A).

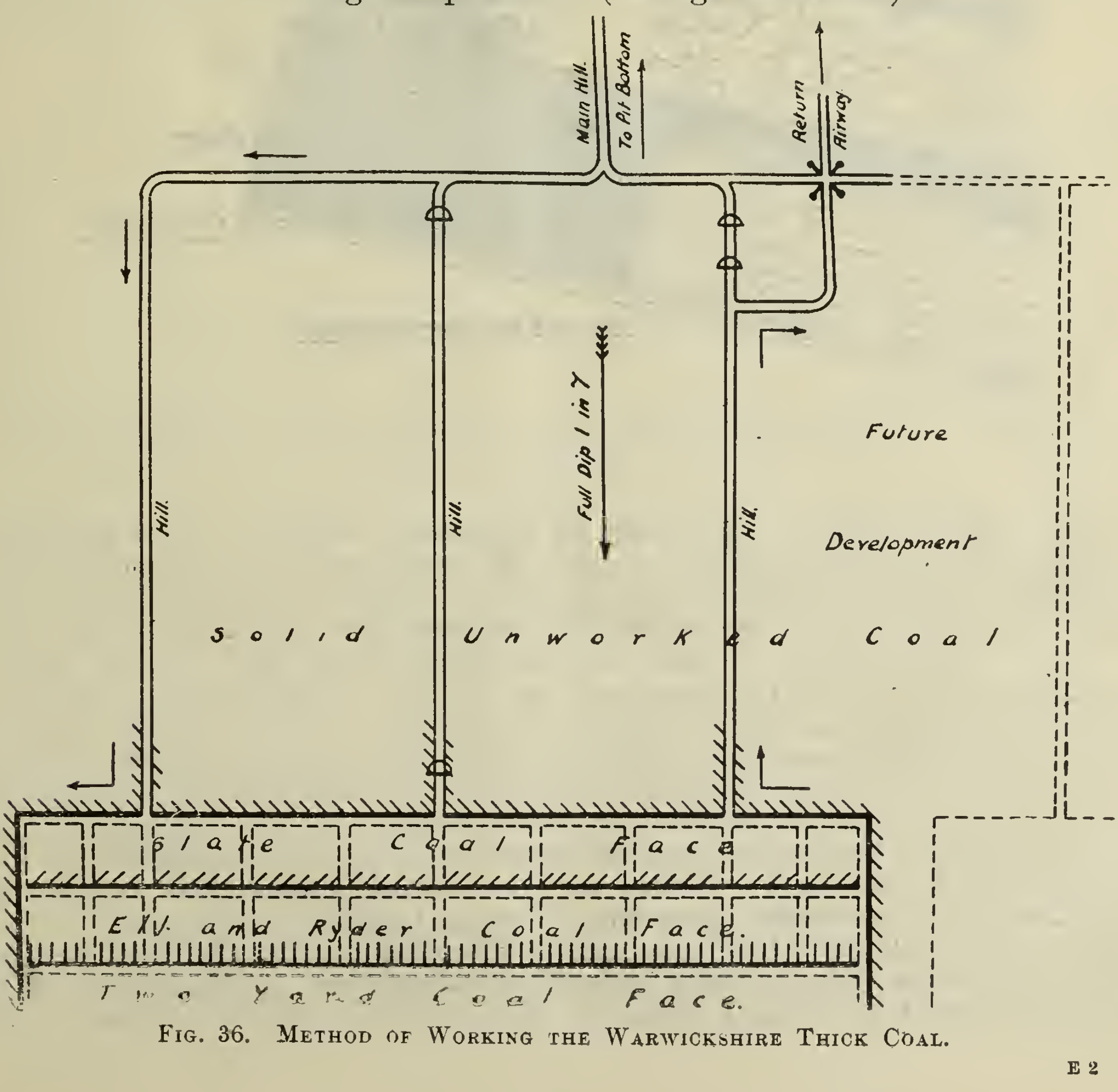


Fig. 36. Method of Working the Warwickshire Thick Coal.

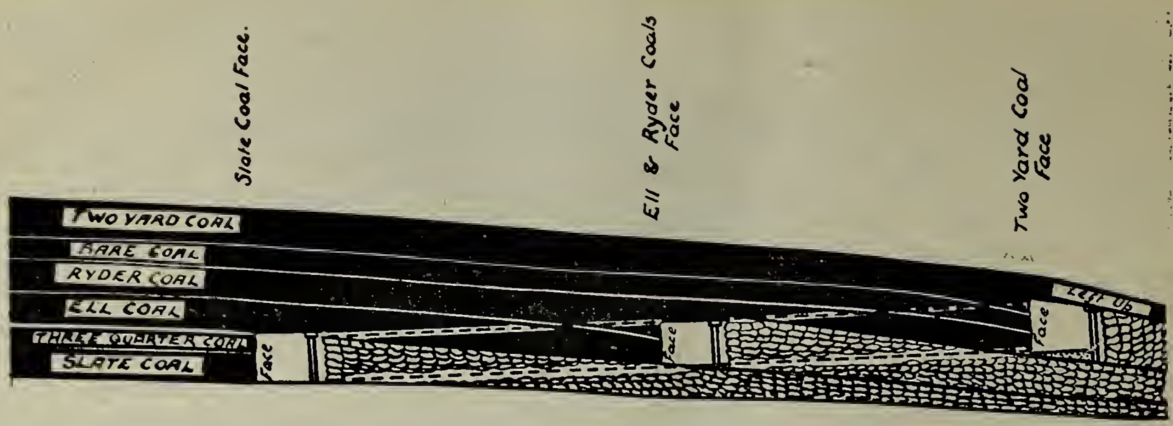


FIG. 36A. METHOD OF WORKING THE WARWICKSHIRE THICK COAL.

A fairly rapid movement of the face seems to be essential to success and a good deal of careful regulation is required to prevent cutting up in the roof (*Q.* 9305, 9794, and 12,084).

At Griff Colliery, Mr. Browne informed us, it occasionally happened that the Two Yard Coal was worked in conjunction with the Ryder Coal. After a time, for commercial reasons, the working of the Ryder had to be discontinued, and Fig. 37 shows the method adopted in continuing work on the Two Yard face. Incidentally it should be noted that whenever this occurred a fire broke out shortly after the Two Yard face crossed the point where the Ryder face had been stopped, "say "eight or nine weeks previously, due no doubt to the crushing and heating up on the "edge of the solid coal" (*Q.* 9794).

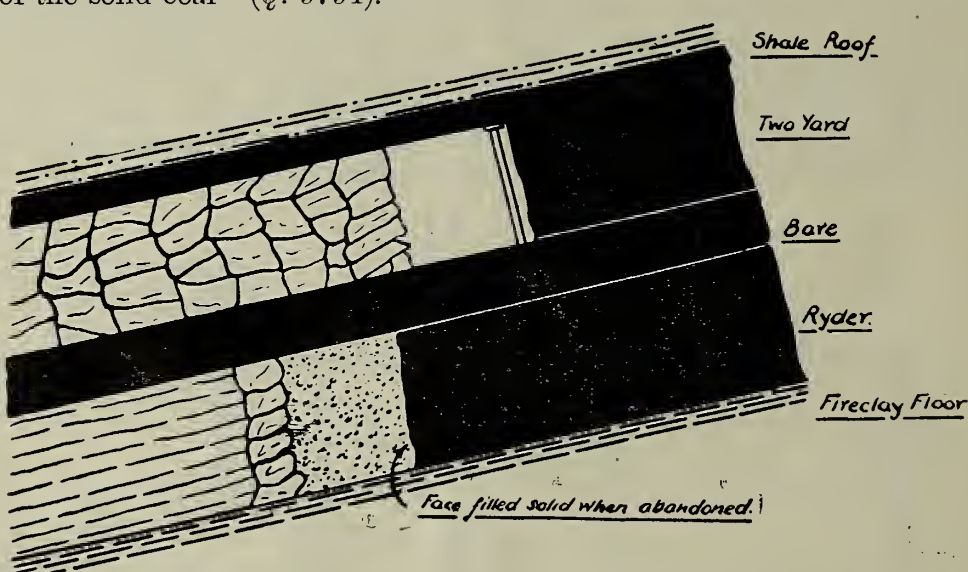


FIG. 37. METHOD OF WORKING THE TWO YARD COAL OVER AN ABANDONED RYDER COAL FACE. (*Q.* 9794.)

COAL LEFT IN WASTES.—No matter what system is adopted to work either the Thick Coal of Warwickshire or any of its single seams, there is at present a certain proportion of the coal unavoidably left behind in the wastes. In the north where the Seven Foot and Bench Coals are worked independently, part of the top coal is left in each case to form the roof. This remnant crushes down in the waste and is undoubtedly responsible for the gob-fires in that district. In the Thick Coal workings coal is lost for several reasons. In working the Slate Coal, in the method described above, it sometimes happens that a fall takes place, that is a fall from the Ell Coal above. Such a fall may have to be left and, should this happen, in all probability a gob-fire will be found, either incipient or active, when the second working (*i.e.*, the Ell and Ryder face) reaches the point where the fall took place (*Q.* 12,084). In this connection Mr. Browne said: "In the past, most of the gob-fires have occurred in "the Slate Coal wastes where large falls of Ryder Coal have taken place." As a result, a considerable area of coal may have to be headed round and built off, and this in turn may have an adverse effect in working the last face, *i.e.*, of the Two Yard Coal. The Bare Coal, lying between the Two Yard and the Ryder Coals, is an

inferior coal having an average thickness of 1 foot, and in many cases is not sent out but is taken down to form the packs for the last working (*Q.* 9345). This is undoubtedly a primary cause of the heating usually encountered in the subsequent working. Part of the top coal of the Two Yard Seam is left up. The third face is frequently difficult to maintain and as a rule breaks down, a large percentage of the Two Yard Coal being lost thereby (*Q.* 12,084). Inasmuch, however, as this occurs in the final working and as we had no evidence of heating in the Two Yard Seam waste either when the coal is worked independently or as a part of the whole thickness, it may be taken that the coal so left is not conducive to fires (*Q.* 9959).

Crushing of Pillars.—Spontaneous ignition of the coal in those mines in Warwickshire where the Thick Coal is worked is much more common in the roads driven in the solid than as the result of coal left in the goaves (*Q.* 9388). The main haulage roads and the return airways are commonly driven in one division or other of the Thick Coal and until comparatively recently they were set out in pairs much too close together. Again, it was the custom to drive "spout-holes" across the main roads, so forming diamond and triangle-shaped pillars, and it is in respect of those pillars that the greatest trouble from spontaneous heating originates. The pillars are too small; they crush and ultimately become heated (*Q.* 9390). Thus *Mr. Jackson* said: "Our chief trouble in the matter of spontaneous combustion is in the main "road pillars due to the fact that they have been made too small. The weight "crushes them, grinding is set up, to be followed by air leakage and subsequent fire. "In most instances these fires will give the most trouble between the intake and "return airways, in the neighbourhood of doors, stoppings and overcasts, or where "the intake air has a chance of making a short circuit through the breaks of thin "pillars, to the return" (*Q.* 9390 and 9459). He added: "The bigger the pillar, "the less likelihood there is of it smashing, but I still think the breaks would form "close to the side and parallel to the road" (*Q.* 9416). Mr. Browne described several cases of fires in main roads due to the crushing of pillars, caused by their being of a size insufficient to withstand the pressure adequately, and after describing one particular case, remarked: "This fire is typical of many at this colliery" (Newdigate) "as regards the inadequacy of pillars, and it would only be repetition to give other "instances" (*Q.* 9794).

Packs.—It might be thought that in a retreating method of working, in view of the waste being left behind and the working roads continually diminishing in length, attention paid to packs and packing would be a matter of secondary importance, but this is not so. As the coal is worked in three successive faces or layers it is of the utmost importance that the two lower wastes should be thoroughly, systematically, and efficiently packed. Here, as elsewhere, inattention to packing and gobbing results in fires (*Q.* 9794). In this concatenation of coal beds where the intervening strata are comparatively thin, the question of packing material becomes a serious one, and very considerable expense is incurred in transporting material from the surface to the working faces. Mr. Browne stated that "the method now adopted of leaving the "Slate Coal holing clunch untouched, and filling up the wastes as far as possible with "old boiler ashes, burnt spoil heap refuse or shale, leaving the Ell Coal intact, has "practically eliminated gob-fires betweeen the Slate Coal and Ryder. The cost of "importing such material is high, but the effect produced is practically that of "hydraulic stowage, viz.:—the prevention of falls in the wastes and the exclusion "of air, while the difficulties connected with the disposal of superfluous water are "avoided. The same remarks apply to the Ryder waste. Owing to the rapid lifting "of the floor, it is not a very difficult matter to fill the dip side up practically solid "with non-combustible material."

Mr. Jackson's practice is to build systematic packs in every seam. He put 4-yard and 3-yard, wayhead packs in the Slate Coal, and he built 4-yard wayhead packs in all the back seams with a waste of 4-yards and 3-yard waste packs (*Q.* 9355).

Leakage of Air across Gateways, through Packs and Wastes.—In spite of the fact that the waste is left behind in the retreating system, it was admitted by witnesses that there was a tendency on the part of the air current circulating the coal faces to draw back to a certain extent into the gob. Mr. Bailey declared that a system of auxiliary fans, placed inbye at Exhall Colliery, is instrumental in reducing leakage of air to a minimum across goaves and through doors and imperfectly stowed crossheads (*Q.* 12,084).

A theory was propounded by Mr. Jackson and supported by Mr. Browne that incipient heatings, and it might be fires, on a main road were caused, even in the absence of thirls, by the wafting of air caused by the passage of tubs. The conditions necessary for such outbreaks are a small sectional area in the road, breaks in the coal, and the frequent passage of trains of tubs moving at a fairly high speed. Mr. Jackson described the action as "blowing in at one moment and puffing out when the train " comes back. . . . . There is a breathing which sets up a fire, but very seldom " (*Q.* 9408). Mr. Browne, in describing a fire in a main road, said that " the " roadway was too small, and the sets of tubs passing rapidly up and down would " cause inspiration and respiration of air at the breaks where the powdered coal was " most in evidence " (*Q.* 9794). (*See also* Figs. 35 and 35A.)

Timber left in Wastes.—Very little was said with regard to timber in the Warwickshire pits, but it was made clear to us that here, as in other districts, the dangers arising from the presence of timber in the waste are understood and appreciated. In spite of this, however, a large proportion, amounting in Mr. Browne's estimation to 20 per cent., is unavoidably left, but in the northern area the modern practice is to withdraw the timber from the wastes after the new packs are put on; this, of course, enables withdrawal to be effected more completely.

(C) *Preventive Measures.*

(i) *The Methods in operation for Preventing Gob-fires.*

In the opinion of all witnesses gob-fires have been greatly reduced in number and extent by the introduction of the retreating system of longwall, and Mr. Browne declared that in this respect a great advance had been made in the solution of the problem of working the Thick Coal at considerable depths, the essence of success being in the complete stowage of the lower wastes so that the upper seams are kept intact (*Q.* 9794). There are, however, other precautions against spontaneous combustion taken in the district or advocated by witnesses, viz. :—

(1) Permanent roads should be driven either above or below the seam.

(2) Headings in the coal should be driven in the lowest part of the seam with adequate pillars between intakes and returns, and should be large enough in area to pass the necessary amount of air without undue pressure.

(3) Small pillars should be avoided. (In the northern area pillars are formed from 80 to 100 yards square.)

(4) The seams should be worked on the retreating system as described, and sufficient gobbing material should be imported where necessary to fill the goaves efficiently. Again, in the north, the wastes and intermediate packs are so proportional as to secure uniform flexure of the roof and effective consolidation of the packs.

(5) A complete system of special supervision should be adopted to detect the earliest signs of heating or chemical change in the atmosphere, and thermometers and other instruments for measuring heat should be more generally employed. In the absence of fires or heatings the "fire-gang" should be employed on repairs of air-courses and other details of ventilation having for their object the prevention of fires.

(6) Timber should be as systematically and completely withdrawn as practicable. (Mr. Browne found it advisable, in order to prevent breaking down in the Slate Coal waste, to leave a certain proportion of the timber to be ultimately drawn by the stallmen working the Ryder Coal.)

(7) Installation of auxiliary fans in the workings to take the pressure of air off the face, and thus reduce the liability to heating.

(8) Installation of water mains throughout the main roads of the mine.

(9) Avoidance of naked lights in order to prevent accidental ignition of timber, coal, or other combustible matter.

(10) Exclusion, as far as practicable, of air from goaves.

(11) Exclusion, as far as practicable, of coal or coaly substances from packs.

(12) Stoppings in cross-connections between intake and return airways used as travelling ways should be so constructed that percolation of air is completely prevented.

(13) Where possible the goaves to the dip should be allowed to fill with water.

(ii) *The Methods in operation for Dealing with Gob-fires when they occur.*

The symptoms accompanying a heating which occur before the actual outbreak of fire are similar in all respects to those observed in other districts. As a rule, the first sign is a slight haze and sweating or appearance of moisture in the vicinity, on the return side of the heating, due, according to Mr. Jackson, to the heated air from the oxidising coal coming into contact with the cooler air of the ventilating current and condensing. Following on the haze and moisture is the familiar paraffin odour or "stink," and this is speedily followed by smoke and fire (*Q.* 9456). Immediately the first symptom is evident or suspected the official specially retained for this work together with his staff take steps to locate the seat of the heating, and according to its nature and location to deal with it at once. Although underground fires in Warwickshire have been in the past, and still are prevalent, yet owing to the infrequency of fire-damp in explosive quantities they have seldom been accompanied with loss of life from explosions. There is a small quantity of gas in some of the returns and it is also found when driving headings in the solid coal, but the retreating method of working was stated by Mr. Browne to have a tendency to drain away the gas.

After a lengthened stoppage the wastes in the Two Yard Coal get very hot and require frequent blanketing with sand and fine flue dust. This, according to Mr. Jackson, is usually effective in preventing the occurrence of fires. In the case of the Ell Coal, however, if a small heating occurs the usual procedure is to dig it out, as is also done in this seam if the heating should have developed into a small fire. It was stated by Mr. Jackson that if this were not done there was a danger of losing the Ryder and Two Yard Coals as well as the Ell Coal (*Q.* 9312–13). Generally speaking, however, with this exception, it is not the custom in Warwickshire to "load-out" gob-fires; indeed, Mr. Browne stated specifically that on no occasion had he done so, nor had it ever been possible for him to get sufficiently near the fires to dispose of them in such a manner (*Q.* 10,122). If the fire developed and assumed serious proportions, Mr. Jackson said he should seal the particular stall off, head by it, and open out afresh (*Q.* 9484).

The action in regard to fires occurring in the solid coal or in main road pillars is again different, and varies considerably. Mr. Browne said he had dealt with several fires in pillars by the side of an important road by ripping down the shale top until the whole of the coal was buried, the bottom being filled with sand or soft "bind" weathered down by water. This process was effectual in each case, but very considerable dislocation of the work of the districts beyond resulted (*Q.* 9794). Mr. Jackson described how he dealt with some cases of fires in broken pillars by stripping off the loose coal, replacing it with timber chocks, and building sand-packs against the coal supported by timber and in some instances brick walls. These sand-packs are well rammed, are three to four feet thick and are very effectual in preventing leakage of air. Barrel-arching of main roads is sometimes adopted at Exhall Colliery, but, in spite of every precaution, the arching becomes more or less porous and consequent leakage of air occurs.

Mr. Jackson described a system of hydraulic sand-packing which he had adopted in cases of fires in the breaks of old pillars and behind arches. The water-main is tapped and a branch pipe connected to a pipe in the wall of the arch. At a suitable distance up-hill, to get a pressure of a few pounds of water, a box or pipe of 10 inches diameter is inserted in the branch pipe, a funnel leading directly into it at the top, a small flow of water is turned on and sand is fed into the box through this funnel. The mixture of sand and water runs down the pipe and into the breaks and has the double advantage of cooling the strata and filling up the breaks in which the heat is developing. This method was stated by Mr. Jackson to be an excellent one in the case of breaks or gobs, but that behind arching it was not a success, inasmuch as the water washed the packing out, making larger air cavities and aggravating the trouble (*Q.* 9601).

The cementation process has been successfully applied to the strata overlying and adjoining roads where heatings have been a source of prolonged trouble and anxiety, and we are of opinion that in similar difficulties this process offers a satisfactory solution.

4. YORKSHIRE.

Although the Yorkshire Coalfield is one of the most extensive in the United Kingdom the susceptibility of the coal to spontaneous heating is chiefly restricted to a comparatively small area, namely, the South Eastern portion.

This area, surrounding Doncaster, is in close proximity to the eastern boundary of the visible coalfield, and here the coal is worked at a very much greater depth than in other parts of Yorkshire. At the present time fires in the South Yorkshire collieries are of less frequent occurrence than when the Committee was set up, and their number continues on the down grade, due partly to natural causes, but more particularly to the efficient and up-to-date preventive measures which have recently been established. We are of opinion that this field offers an excellent example of how the evils of underground fires due to spontaneous combustion of the coal can be mitigated or completely avoided.

The principal seam of coal now being worked in the area is the Barnsley Bed. This coal, sections of which appear below, is a gassy seam, peculiarly liable to spontaneous combustion, and because of the dangerous combination of gas and fires particular care has to be exercised in working it. It is the only seam in South Yorkshire that need at present be considered in connection with spontaneous combustion.

(A) *Geological Conditions.*

The Barnsley Bed in the Doncaster area is a thick seam, but it is the usual practice to leave unworked a considerable portion of the top coal to form the roof, which breaks down in the gob, and which may or may not be wholly recoverable.

Section of Barnsley Bed.—Brodsworth Main Colliery.

	Ft. ins.	Ft. ins.
Roof :— Blue Bind	—	3 6
Roof :— Dark Bind	—	1 6
COAL	0 4	—
Clunchy Bind	—	3 0
Shale	—	0 0½
TOP SOFTS (with parting)	3 6	—
Light Clod	—	0 5
Dark Shale	—	0 1
CLAY SEAM	0 6	—
Parting	—	—
HARD COAL	2 6	—
Parting	—	—
BRIGHT COAL	2 0	—
"Jacks" Oily Shale	—	0 3
Floor :—Soft Clunch	—	—
	8 10	3 9½

Section of Barnsley Bed at Messrs. Barber Walker and Company's Bentley Colliery, Doncaster.

(*Q.* 13,444 ; Mr. R. Clive.)

	Ft. ins.	Ft. ins.
Roof :— Bind with Ironstone Nodules	—	—
Roof :— Blue Bind	—	2 0

	Ft. ins.	Ft. ins.
Top Coal (Day Bed) - - - -	1 6	—
Soft Clunch - - - - -	—	2 0
Soft Clunch with dark bind and batt. - -	—	1 6
Top Soft Coal - - - - -	3 10	—
Clay Seam Dirt - - - - -	—	0 4
Barnsley Seam { Hards - - - -	2 8	—
Barnsley Seam { Softs - - - -	2 4	—
Soft Dirt - - - - - -	—	0 4
Total Thickness - - -	10 4	4 2
Floor:— { Hard Stone Clunch - - -	—	2 0
Floor:— { Sandy Bind - - - -	—	—

The Top Soft Coal is left on as a roof in the face, but is ripped in the gate-roads.

Section of Barnsley Bed.—Bentley Colliery.

(*Q.* 12,332; Mr. Bailey.)

	Ft. ins.	Ft. ins.
Roof:—Binds - - - - - -	—	—
Coal (Day Bed) - - - - -	1 6	—
Clod or Fireclay - - - - -	—	2 6
Coal - - - - - -	0 1	—
Dark Clod - - - - - -	—	1 0
Clod or Fireclay - - - - -	—	2 0
Top Softs - - - - - -	3 9	—
Light Clod - - - - -	—	0 4
Dark Clod - - - - - -	—	0 1
Hard Coal (with parting) - - - -	3 3	—
"Jacks" (Bastard Cannel) - - -	—	0 5
Bottom Softs - - - - -	1 10	—
Dark Fireclay - - - - -	—	0 8
Floor:—Stone Clunch - - - - -	—	—
	10 5	7 0

Section of Barnsley Bed.—Hickleton Main Colliery.

(*Q.* 12,286; Mr. Bailey.)

	Ft. ins.	Ft. ins.
Roof:—Shale with Ironstone Bands - - -	—	21 0
Top Softs - - - - -	0 10	—
Dirt ("Bags"). - - - - -	—	0 2
Clay Seam (inferior) - - - -	0 6	—
Parting - - - - - -	—	—
Hard Coal - - - - -	2 8	—
Parting - - - - - -	—	—
Bottom Softs - - - - -	2 3	—
Bat - - - - - -	—	0 3
Floor:—Shale - - - - - -	—	—
	6 3	0 5

Section of Barnsley Bed.—Cadeby Main Colliery.

(*Q.* 12,283; Mr. Bailey.)

	Ft. ins.	Ft. ins.
Roof:— Bind and Shale	—	7 0
Roof:— Stone Bind	—	1 0
Roof:— Clod	—	2 0
Coal (Day Beds)	0 11	—
Bag Dirt	—	0 10
Coal (Bags)	1 0	—
Parting	—	0 1
Top Coal	1 11	—
Parting	—	—
Clay Seam	0 4	—
Parting	—	—
Hard Coal	3 0	—
Parting	—	—
Bottom Softs	2 0	—
Floor:—Dark Clod	—	2 0
	9 2	2 11

Immediately above the seam is a bed of bind, variable in hardness, and containing in some cases ironstone nodules. It would constitute, for the most part, a moderately good roof, but as it is considered impracticable to work the whole section of the seam up to this level in one working, the Top Coal and the Top Soft Coal are usually left up, the "clunch" between these two coals being of such a soft and uncertain nature that it could not be left as a roof. Several attempts have been made to work the top coals in one operation with the main Barnsley seam, but owing to the thickness and consequent height the dangers to the workmen from roof falls are greatly augmented. In addition, the material available for packing is both too friable and too scarce to allow of the construction of efficient packs to the height required (*Q.* 9077 and 13,449).

Mr. J. T. Greensmith, General Manager of the Brodsworth Main Colliery, said that when once the Top Coal was broken through, the roof, consisting of false unlaminated binds, is a bad one, and when falls occur large cavities are formed (*Q.* 9083). These cavities, as will be seen later, have an important bearing on the method of dealing with an outbreak of spontaneous combustion in their vicinity.

Breaks in the roof extending on either side of the gate roads are common both in a horizontal and in a vertical direction (*Q.* 9083).

A seam of coal which is of no present economic value, called the Day Bed Seam, is met with throughout the area at a varying height above the Barnsley Bed. At Brodsworth Main Colliery shaft the Day Bed Seam is separated from the Barnsley Seam by 45 feet, but in certain districts of the workings it comes down to within 4 or 5 feet thereof, introducing a factor in the proneness of the Barnsley Bed to spontaneous combustion which cannot be ignored. Mr. Greensmith described the Day Bed Seam as being 20 inches thick, of a highly bituminous character, and very liable to fire. When falls take place up to this seam, it has been noticed that considerable quantities of gas are given off therefrom (*Q.* 9077).

Mr. G. Poole, His Majesty's Inspector of Mines, considered that the Day Bed Seam might have a similar blanketing effect in the goaf to that which the "Hussle" has in North Staffordshire (*Q.* 2316), (*see* page 35).

Quantities of oil exude from the roof, stated by *Mr. T. H. Bailey,* of Birmingham, to emanate in Cadeby Main Colliery from the "Bags" Dirt, and this oil causes the roof to be treacherous in the stalls and gate-roads, increasing the difficulties in working the seam. The oil, which has a smell like tub grease, is collected in various parts of Brodsworth Main Colliery in barrels and sent out of the pit (*Q.* 9703 and 12,283). The inclination of the Barnsley seam is regular and gentle, and at

Brodsworth the dip from the shafts to the faces is about 1 in 60. The depth to the seam in this portion of the field is considerable, viz., 595 yards at Brodsworth and 639 yards at Hickleton Main. The weight of the superincumbent strata is consequently great and is reflected in the comparative ease with which the coal is worked, and in the manner in which the goaf closes. The frequent fires in the early history of Brodsworth Main Colliery (when the seam was being opened up) were due, in Mr. Greensmith's opinion, to the first and second " weights," and the present comparative immunity is at least partly due to the fact that a considerable area of goaf has been formed, and that the weight is now thrown back more quickly on to the waste (*Q.* 13,368–13,377).

In the opening up of Brodsworth Main Colliery, difficulties were encountered by reason of the faults which, in that area, are of much more frequent occurrence than in other collieries in the district. Three sides of the pit were stated by Mr. Greensmith to be practically cut off by faults, and he assigned to the faulty areas in the mine the greatest tendency to fires (*Q.* 9099 and 12,290). Faults are responsible for irregularities in working, especially in the longwall method, and ventilation is often restricted or retarded thereby.

The coal in the vicinity of faults is friable and inferior (in the case of Brodsworth it assumes the consistency of blacklead (*Q.* 5149)),and these facts lead to portions of the coal being left unwrought. The Cadeby Main explosion, which occurred in July 1912, was directly traceable to a fire caused by the presence of a fault (*Q.* 12,283). The only case of spontaneous combustion recorded at Hickleton Main occurred in a corner of the upthrow side of a series of small faults where coal had been left, three years previous to the outbreak, near certain old workings which crossed the faults (*Q.* 12,286) (*see* Fig. 40).

Mr. Poole's opinion was that fires occurred near faults because of the friable and inferior nature of the coal, and also because of the cavities which result, enabling the air to travel along and feed the fire, or allowing the accumulation of a sufficient amount of air to cause spontaneous combustion (*Q.* 2335–6).

Without exception, witnesses were convinced that faults were direct contributory causes of spontaneous combustion, and emphasised the care which should be exercised in securing the complete removal of all coal, good and bad, and in the complete stowage of the cavities formed, specially against the side of the fault itself (*Q.* 9145–12,290 and 6374).

(B) *Mining Conditions.*

METHODS OF WORKING.—The method of working universally practised in the southern area of Yorkshire is longwall, and it is customary to work the coal outwards, opening out the faces immediately the shaft pillar area is formed. The following description of the method of working the Barnsley Seam at Brodsworth Main Colliery is taken from Mr. Greensmith's evidence, and may be assumed to be fairly representative of other colleries in the same district. (*See* Fig. 38.)

At that colliery the coal is got on the cross or " awn," as it is locally termed, that is a considerable angle, 35–40 degrees, off the cleat of the coal. (It may here be noted that in the opinion of both *Mr. Greensmith* and *Mr. Bailey*, the design of the shaft pillar and the method of opening out the first faces were responsible for the occurrence of many of the earlier fires that occurred at Brodsworth Main Colliery, but it should be remembered that fires were not then anticipated (*Q.* 9073, 13,373 and 12,290).) The gateways are packed out at 50 yards centres, and are practically at right angles to the working face. The cross-gates are made and maintained 120 yards apart, and the main roads each cut off the cross-gates every 450 yards, thus allowing and limiting ten stalls to a ventilating split. Of the full section of the seam (9 ft. 5 ins.), only 5 ft. 3 ins. of coal is actually worked, and the section is made up of the following items :—Top coal, 3 ft. 8 ins. ; Clod, 3 ins. to 10 ins. ; Hards, 2 ft. 3 ins. ; Softs, 3 ft. ; Dirt (floor), 3 ins. to 7 ins. When properly manned, the stall has eight men in each of the two coal drawing shifts, which is equal to six yards of face per man. The coal when got at the proper angle is easily mined, and very little holing is necessary. The timber is set under the Top coal, the props being 5 ft. 6 ins. apart and in line with the tub road, bars being set where and when necessary. Several attempts have been made to work the Top coal, but with no success (*see* page 74).

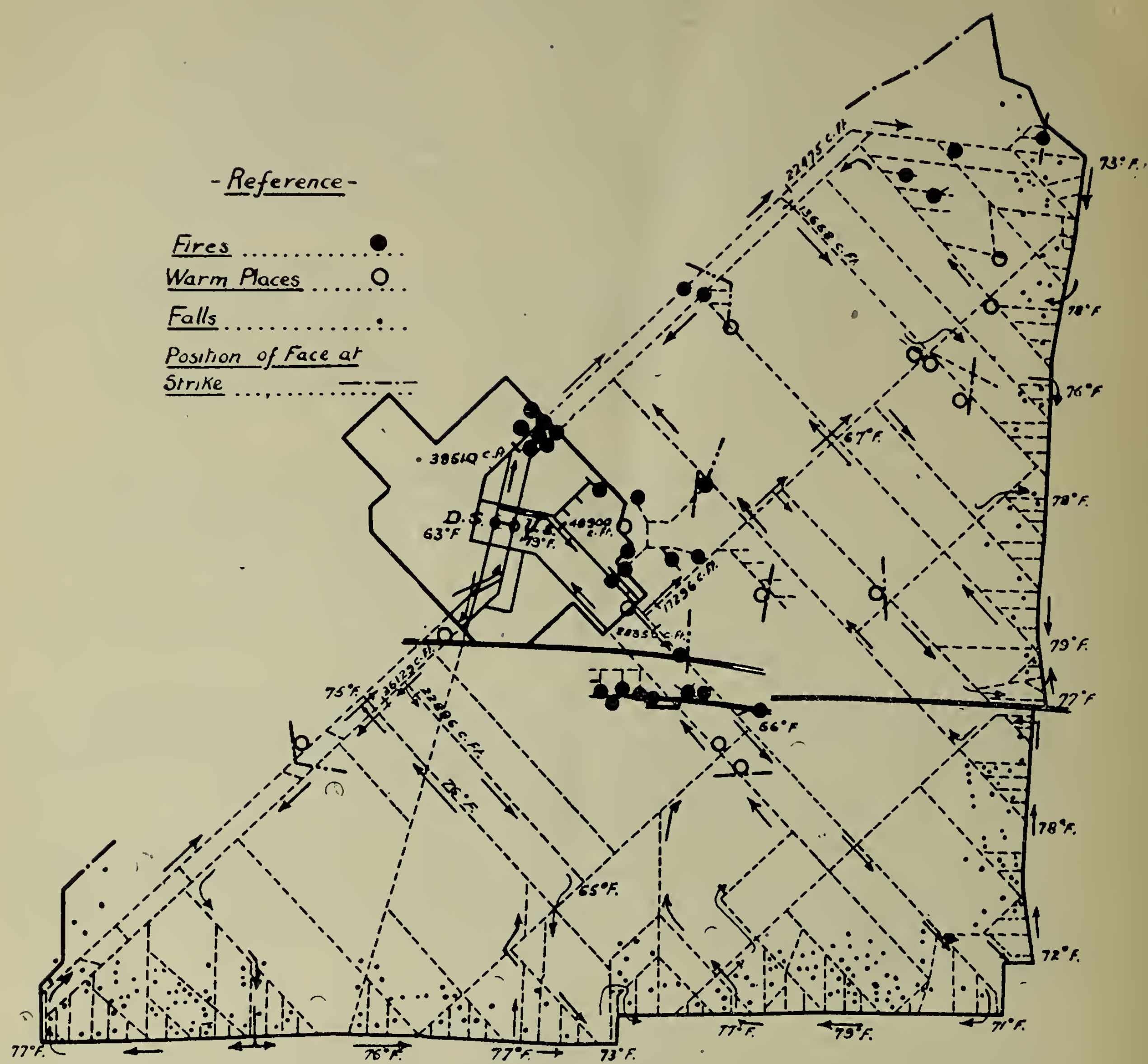


FIG 38. BRODSWORTH MAIN COLLIERY. PLAN SHOWING WORKINGS, VENTILATION, GOB-FIRES, AND FALLS TO FACE.

Note.—The average difference between the wet and dry bulb is approximately between 8° and 10° at the return end of the faces and in return airways. The variations in the intakes follow those of the surface.

The experience at Brodsworth has been that fires do not occur where the Top coal has been left intact, which can only be efficiently achieved when the stalls are packed solid. The system of ripping is that the colliers take down the Top coal in the gates, and this is filled out and sent to the surface, following which, stone lips are taken by contractors according to conditions. As this is being done the floor is being constantly raised. By the time the stall is 100 yards from the crossgate, the gateside packs are buried; when 150 yards from the cross-gates the Top coal also is buried. Great attention is paid to keeping the faces straight, the "weight" thereby being evenly distributed and falls at the face reduced to a minimum. When falls in stalls do occur, they are at once reported, and particular care is taken that no rib of coal is left, and that all timber is extracted when the stall is being recovered or again opened out. Special forms are provided at Brodsworth Main Colliery for reporting the occurrence of such falls and for recording the work done during their clearance and recovery. Mr. Greensmith laid great stress on the importance of such procedure, and copies of the forms in use appear below (*Q.* 13,404).

Forms referred to in Questions 13,401–5.

(Form No. 1) Serial No. Brodsworth Main Colliery, Near Doncaster. Date.................... To Report on FALL TO FACE in No. Stall. Date when fall occurred............... Special measures taken with fall— Signed........................ Date........................... Please return to me when complete. Manager.	(Form No. 2) Serial No. Brodsworth Main Colliery, Near Doncaster. Date..................... To........................ Deputy..................... District Fill in the necessary particulars concerning the FALL OF FACE in No.........Stall. Date when fall occurred..................... Length of fall...................................... Date when recovering commenced........ Date when recovering finished............ Yards of recovering paid for............... Distance down the gate in yards......... Distance along face to the fall from gate end....................................... Which Bench the fall occurred in........ Has it broken across gate end ?........... State what material was left under the fall and how dealt with................. State cause of fall........................... Signed........................... District.......................... Date............................. Please return to me when completed. Manager.

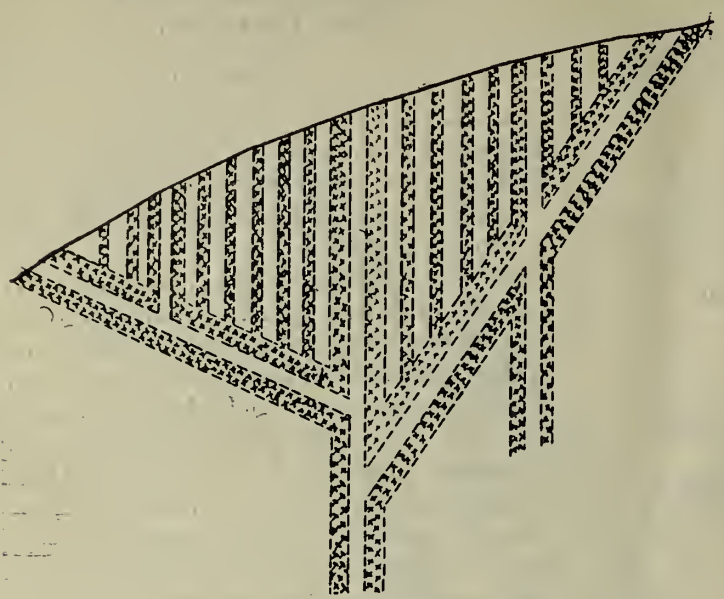
At Bentley Colliery a similar method of working is adopted with the Top Softs again left as a roof. No coal is filled out of the gobs, but the Top Softs are ripped in the gates and sent out of the pit. The Colliery was opened out by headings driven in the Barnsley Seam through the shaft pillar, and one continuous face was opened out on the west, south and east sides. Subsequently the face was split up into panels allocating a length of face of from 550 to 850 yards to each main road, the main road in each case being in the centre of the district with a travelling road running parallel, and forty yards distant (*Q.* 13,444).

At Hickleton Main Colliery, according to Mr. Bailey, a method of working is in operation which approximates to the breasting system of North Staffordshire. He said of it :—" It is remarkable that hitherto under this system of working no fires have " resulted, and I am inclined to the opinion that it is in consequence of only some " 18 inches to 2 feet of Top Softs being left over the wastes (25 yards in width with " no pack), and thus the roof is free to settle down, effectually preventing air leakages " through the goaf. This coal and dirt fall solid, and the breaks occur in the shale " with ironstone bands above, to which the heat rises and does no mischief " (*Q.* 12,286).

While it may be that there is something in what Mr. Bailey says, the fact should not be lost sight of that numerous instances have occurred where fire has broken out in the solid coal on road-sides and edges of pillars, showing that there must be some difference in the constituent parts of the seam.

Packs.—The view is generally held that efficient packing is a very necessary precaution to take in mines liable to spontaneous combustion, and it would appear that great attention is paid to this feature in South Yorkshire. In working the Barnsley Bed the packs are most frequently built up to the Top Softs, and when

this is done in an efficient manner it is said that those portions of the seams left unworked settle gradually and gently into the waste without occasioning violent breaks, making it possible for such coal to be taken out in a second working at a future date (*Q*. 13,458). Fig. 39 illustrates the system of packing in operation at Bentley Colliery, a system which, according to the agent, Mr. R. Clive, is strictly adhered to.



Gate packs and cross-gate packs, 3 yards wide. Gob packs, 2 yards wide, 20 foot centres.

Gates 44 yards centres. Cross gates 150 to 175 yards centres.

Fig. 39. Method of Working and Packing at Bentley Colliery (*Q*. 13,445).

On the question of the utility of centre or waste packs, *Mr. G. Poole*, His Majesty's Inspector of Mines, expressed the opinion that gob roads should be separated by such a distance that the centre packs could be eliminated, in which case, he thought, the "weight" would not be thrown on to the face. He admitted, however, that such a practice might not be possible in every mine, and considered that it would have to be a matter of experiment in each case (*Q*. 2265). He was in agreement with other witnesses in stating that gate road packs should be as wide as possible, and suggested 4 to 6 yards as a suitable width. He also expressed the opinion that packs should be treated as to their inside walls with a sealing of clay or other plastic earth (*Q*. 2271). *Mr. H. Ross*, Checkweighman, and formerly an underground official at Maltby and Cadeby Collieries, emphasised the importance of efficient packing, and recommended that gate road packs should be built to a width not less than three times the height of the working (*Q*. 6621). The composition of the packs depends on the material available and at Brodsworth Main Colliery "they consist of floor dirt and top clod, "together with the slack made in mining the coal." (Since 1917 the slack has been sent out of the pit.) "The floor of the seam at this colliery is generally very dirty, "being in most cases as fine as sand. In addition to the dirt made in the stalls, all "the refuse from the ripping, road repairs, &c., is sent in and stowed practically solid "up to the Top Coal" (*Q*. 9074).

A case of a fire occurring in a gate road pack was mentioned by Mr. Poole as due to a wood chock having been left in together with a certain amount of small coal, and he urged that coal should not be permitted to form part of the composition of packs (*Q*. 2282 and 2341).

Coal left in Wastes.—Although a very large proportion of the Barnsley Bed is left in the first working, some of which ultimately falls behind in the waste, it was not considered that this coal contributed to spontaneous combustion to any great extent, it being pointed out that by the system of ripping the roads, the packs and top coal were soon buried, effectually preventing any leakage of air through the goaves. Thus Mr. Bailey said that he had not experienced any case of fire occurring in the top coal which in the normal course of working had fallen into the waste in the Cadeby Colliery (*Q*. 12,282).

With regard to slack, he did not think that its removal from the waste would make much difference, and on its being suggested that once small coal is laid on the floor it did not matter how it had been laid, he replied:—"There is this difference; the small coal

" or slack which is thrown back from the working is not heated ; but with the breaking " of the roof and the air getting through, it is heated and it falls on to the ground in " a heated state. That is why I think it fires " (*Q.* 12,331). He, however, in common with other witnesses was strongly of opinion that all small pillars left in the workings or against faults should be completely removed. As a matter of fact Messrs. Greensmith, Criddle, and Clive all emphasised the fact that they made it one of their chief endeavours to extract all coal, and *Mr. Criddle*, Manager of Brodsworth Main Colliery, said :—" It is not always possible to remove all coal, but my orders are to get it out " no matter at what cost " (*Q.* 5701). *Mr. Probert* attributed the freedom from fires of Hickleton Main Colliery to the complete removal of all coal (*Q.* 6701).

Crushing of Pillars.—It has been stated that the usual practice in South Yorkshire is to open out longwall faces immediately the shaft pillar has been completed, and it rarely happens, at least in the normal working of the mines, that pillars of coal are left. As has been indicated, the Barnsley Bed, where liable to spontaneous combustion, lies at a considerable depth from the surface, and the pressure of the superincumbent strata on pillars of inadequate size is such that fires frequently occur in the breaks caused by the pressure, and at the corners of such pillars. Thus Mr. Greensmith said : " The fires in the shaft pillar have not caused us " very serious trouble. Heating usually takes place in the fissures caused on the " edge of the pillars by the pressure, small particles of coal and clod falling into " the crevices. Possibly heating starts up mechanically. Oxidation is set up, and " with the least amount of air possible passing through the breaks, combustion is " started. In such cases it has been the custom to fill off the loose coal to the last " break, and we have had no further trouble. After the experience gained, larger pillars " would be left, and as few connections possible made between the intake and return " airways (*Q.* 9115).

Mr. Bailey, in describing the conditions at Brodsworth Main Colliery, ascribed the occurrence of fires in the shaft and extension pillars (*see* Fig. 38) to the fact that the former was originally cut out on the cleat of the coal, and that the irregular working away from the pillar edges, which he said was apparently inevitable, brought very unequal loads upon the small pillars of the opening-off levels, with resultant crushing (*Q.* 12,290). The same witness declared that at Bentley Colliery the system of leaving small pillars between a pair of main levels skirting the edge of the shaft pillar had been abandoned in favour of working directly away from the solid pillar edge. He said that the result was to reduce considerably the liability to fires in the vicinity of shaft pillars (*Q.* 12,332).

Several witnesses suggested that a remedy might be found in thoroughly and efficiently packing all round the shaft pillar and other pillars, and in stowing those roads which had been cut through the pillars but had since been in disuse (*Q.* 2293, 9191, and 12,332). On the other hand, Mr. Greensmith held the view that such roads should be kept open (*Q.* 9262).

Leakage of Air across Gateways, through Packs and Wastes.—Witnesses from the Yorkshire area were fully alive to the importance of preventing leakage of air from airways.

The practice of ripping the roads and of burying gate-road packs and top coal was claimed to be most effectual in eliminating, or at least greatly reducing, the leakage of air into the goaves (*Q.* 2320, 2352, 9080, and 13,447). *Mr. Clive* said that the majority of fires at his colliery (Bentley) occurred in the gob, started and propagated by " breathing " from the face, and that such occurrences almost invariably accompany a neglected fall at the face (*Q.* 13,446). Mr. Greensmith held the same view (*Q.* 13,391). Details were given by the last-named witness of a fire which occurred at an overcast, which he said was due to leakage of air from the intake through the foot of the overcast into the return (*Q.* 9202). The remedy would appear to be to avoid such leakage by making solid headings for overcasts and undercasts and separating the intake and return airways as much as possible (*Q.* 9078). Several cases were quoted where fires were caused by air pulling through old disused roads which had not been securely sealed off (*Q.* 5152, 12,290, and 13,446). Another fire (Fig. 40), the only occurrence at Hickleton Main Colliery on record, was described by Mr. Bailey. A fall had occurred and the interrupted air current made its way through the new unconsolidated goaf on one side of a pack which had been prevented from closing down by the presence therein of timber, and possibly by some coal having been left in the old goaf in the neighbourhood of faults. This air penetrating

into the goaf having all the elements suitable to spontaneous combustion, led, in Mr. Bailey's opinion, to the outbreak (*Q.* 12,280).

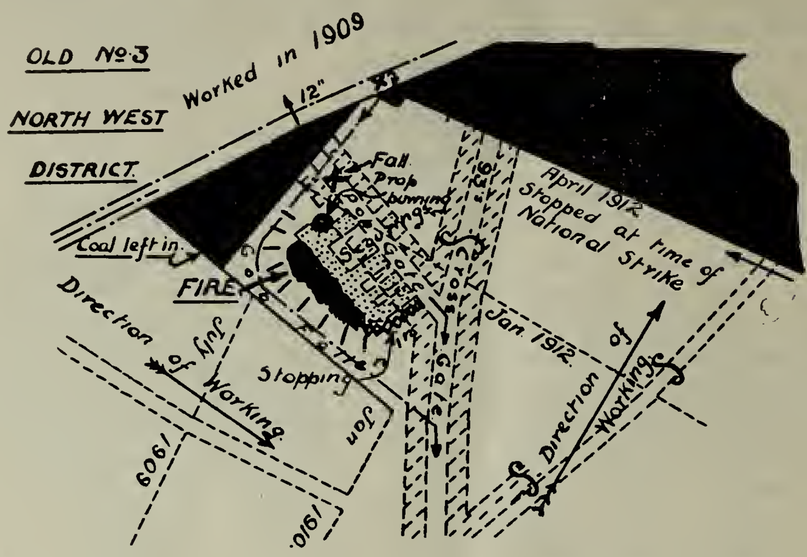


FIG. 40. HICKLETON MAIN COLLIERY (*Q.* 12,280). SKETCH PLAN SHOWING POSITION OF FIRE REFERRED TO.

TIMBER LEFT IN WASTES.—Although there was a certain amount of dubiety in the minds of witnesses as to whether or not timber could be held primarily responsible for spontaneous ignition in goaves or in disused roads, there was complete unanimity as to the desirability of leaving none behind. Both at Brodsworth Main and at Bentley Colliery orders are issued for the complete removal of all timber, whether in the form of props or chocks, and it was asserted that great reductions in the quantities left behind were being effected. Where difficulties are experienced by the stallmen in the way of timber extraction, they are instructed to apply for official help, and in some cases a special rate is allowed per prop drawn.

As has been indicated, there are two schools of thought as to the part played by timber in the occurrence of spontaneous combustion. In almost every case of fire, timber is found at or near the outbreak, and Mr. Poole thought that the primary cause of all fires was timber left in the gob (*Q.* 2261). Mr. Greensmith opposed this view, but declared that the timber prevented an even settlement of the roof, and in this he was supported by Mr. Clive, who said : " Although charred and burnt timber has often " been found when excavating fires, I am not inclined to think that timber is the primary " cause. If props are left in, it means that the coal breaks up all round and forms " small coal, and that creates a cavity. You would get the same conditions with a " steel prop as with timber."

(C) *Preventive Measures.*

(i) *The Methods in operation for Preventing Gob-fires.*

It was claimed by *Mr. Greensmith* that he had effected a steady and continuous decrease in the number of fires by the adoption of the following organisation and methods, viz. :—

1. The appointment of a special official who is provided with a staff of men, the sole duties of whom are the investigation twice during each eight hours' shift of the slightest symptoms of heating, the taking of necessary and immediate action when heating occurs, and the removal of all falls at the coal face.
2. The provision of an adequate supply of materials, such as girders, bolts, covering plates, ventilating pipes, fire extinguishers, and telephones.
3. Continuous and efficient stone-dusting of roadways.
4. The appointment of a resident chemist, whose duties consist in the systematic taking of samples of mine air and recording the results of analyses, and recording temperatures, &c. taken in the mine.
5. Recording the erection and removal of all wood chocks.

6. The maintenance of good airways close to and parallel with faults, so that, should heating take place, the airway is available for the removal of the products of combustion and for getting at the fire if necessary.
7. The systematic recording of all falls.

In connection with No. 7, Mr. Greensmith laid great stress on the importance of the strict observance of this rule, saying:—

"By having a record of the falls, not waiting till we get heating, and then having " to go into it when it is too late, we contend that we are pretty certain that we get " there first."

"After the falls have been dealt with by the removal of any pillars of coal, timber, " &c., the cavities are filled with soil and bind, special attention being given to " those cases where falls extend into gateways or cross levels. It is very rarely " that we get into any trouble after this operation has been carried out, but, on the " slightest suspicion, samples of air are taken at the face of the fall or crevice, and " the results of the analyses are forwarded to the manager or agent. Up to the " present (1920) 50 fall places have been dealt with in this manner. We feel that " our immunity from trouble is in a great measure due to the steps we are now " taking" (*see also* page 77).

Mr. Robert Clive, Agent of Messrs. Barber, Walker and Company's Bentley Colliery, epitomised the precautions taken there as follows:—

1. The establishment of a special staff, devoted to the searching out and further prevention of spontaneous heatings.
2. The working of the face in straight lines, and its continuous and rapid advancement; the regular building up of packs and the keeping of them as close up to the face as practicable with the object of preventing falls at the face and conducing to the regular and gradual settlement of the superincumbent strata in the gob without the breaking up of the Top Soft coal.
3. Building solid packs, five or ten yards in width along rib-sides and faults with sand packed immediately against the rib-side or fault. Experience shows that an open gobbing against the rib-side does not close up tightly, and allows of open spaces being left through which air pulls, conducing to spontaneous heating.
4. Ripping the roof as quickly as possible behind the face in all gates, cross-gates and main roads, and raising the roads to such a height as to completely bury the pack and eventually the Top Soft coal as well. Usually the pack is buried thirty to sixty yards behind the working face, thus preventing any chance of air pulling through the road-side packs, and causing spontaneous combustion in the gob.
5. The avoidance, as far as possible, of falls at the face, and when one does occur, taking care to extract all the solid coal against the fall, and to put a solid pack under a good roof, joining into the ordinary packs immediately on each side of the fall.
6. When a gate or cross-gate is cut off and discontinued, the withdrawal of all timber (including wood chocks, if any) from the face end, and the building of solid sand and bind packs across the face and out-bye ends of the gate.
7. The thorough stone-dusting of all main roads, cross-gates and returns, and when indications of spontaneous combustion are first discovered, the thorough re-dusting of all roads in the immediate vicinity.
8. The taking of special precautions to ensure that all face timber is drawn, to allow of the roof settling quickly and regularly.
9. The discontinuance of the use of timber chocks at corners where new gates are turned away.
10. The avoidance, as far as possible, of air-crossings.

Mr. Clive considered that the above special precautions, many of which had been referred to by previous witnesses, had rendered the mine at the present time immune from fires arising from spontaneous combustion. Mr. Poole desired, as far as possible, the abolition of the centre packs which are commonly used, and he advocated the sealing of all packs (*see also* page 78). As a further precaution against underground fires several witnesses advocated that the retreating method of longwall working should be adopted where possible (*Q.* 2345, 6451, 6667–9).

(ii) *The Methods in operation for Dealing with Gob-Fires when they occur.*

The method usually adopted by *Mr. Greensmith* at Brodsworth Main Colliery is to dig out the heated material and fill up the resulting cavity with incombustible material.

When symptoms of spontaneous heating (which in this district are identical with those previously described) are discovered, the place where the heating has originated is located by the special staff in consultation with the manager. After careful consideration, it is decided whether or not to insert a stopping or stoppings, the site or sites are determined, and after going into the question of ventilation as to which side of the fire should be attacked, immediate action is taken. Mr. Greensmith stated that in no case which had come under his observation had it been thought desirable or practicable to attempt to stop off a fire (*Q.* 5125). From the point of view of expense, stopping off might be cheaper than digging out a fire, but quite apart from the financial point of view digging out is most frequently adopted because of the greater certainty of complete removal of the trouble. At Brodsworth the fires have occurred in such accessible places that long "scourings" have not been necessary. Where there are signs of the existence of a large fire, it was in Mr. Greensmith's opinion advantageous to drive two scourings into the heated area. He realised the necessity of admitting a minimum quantity of air to the fire, but the comfort and safety of the men dealing with the outbreak had to be considered. He had never found any advantage in temporarily packing up or trying to smother a fire (*Q.* 9167). Canaries are used at Brodsworth, one on each shift, in the vicinity of fires or in the scourings where the men are working, in order to detect the presence of carbon monoxide (*Q.* 9182).

Mr. Robert Clive described the action taken at Bentley Colliery when dealing with various classes of fire. He stated that a large number of fires occurred in the "opening-out" pillars (Fig. 41).

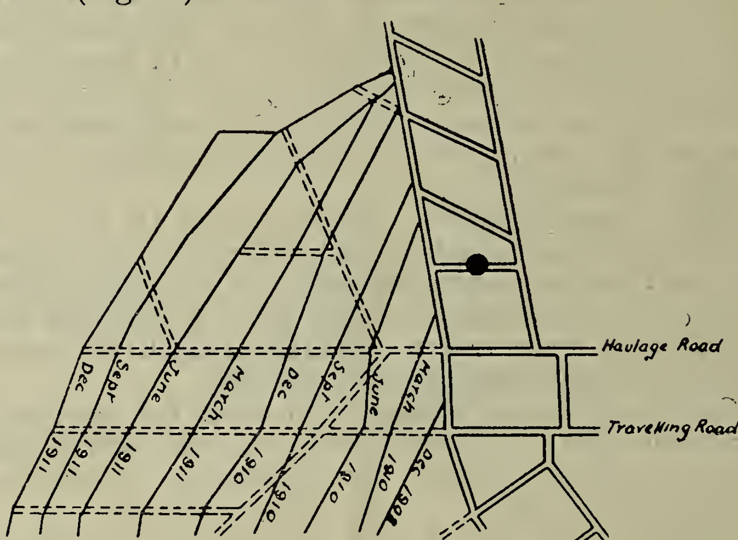


FIG. 41. EXAMPLE OF A FIRE IN A SOLID PILLAR OF COAL (*Q.* 13,446).

These fires were dealt with by taking out the heated material and stowing up the cavity with sand and bind, and facing up with a sand and brick dam let well into the sides beyond the breaks. In some cases the fires were small ones and easily dealt with; in others they were more extensive, and entailed a considerable amount of work before being successfully overcome.

A few fires in the solid coal occurred in slits between the main intakes and main returns; these were similarly dealt with, and a strong dam built at each end of the slit. Mr. Clive did not consider it to be either dangerous or difficult to drive scourings or to excavate the heated material, nor did he think there was any risk in driving into a cavity. This, he said, is usually done from the intake side, the air travelling round the face. He considered this a safer method than driving from the return side in cases where either is possible. It should be noted that these remarks apply solely to fires occurring in solid pillars of coal.

So far as gob fires caused by "breathing" from the face are concerned, the original practice at Bentley Colliery was to scour to the seat of the fire (Figs. 42 and 42A) and fill out the heated ground either from the face or across from the side of the gate.

After all heated material had been excavated, the place was allowed to cool down, and was then packed solid with bind and sand.

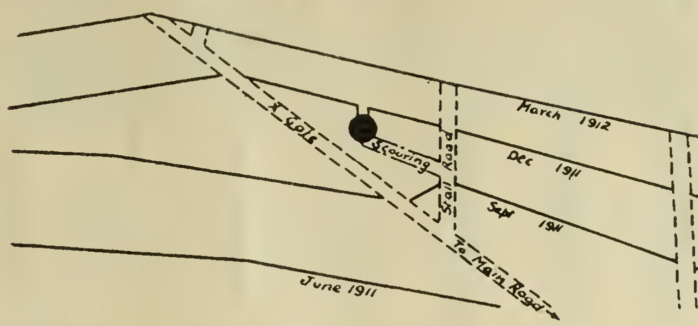


FIG. 42. FIRE OCCURRING IN THE GOB BY "BREATHING" FROM THE FACE. SKETCH ILLUSTRATING SITE OF FIRE AND SCOURING (Q. 13,447).

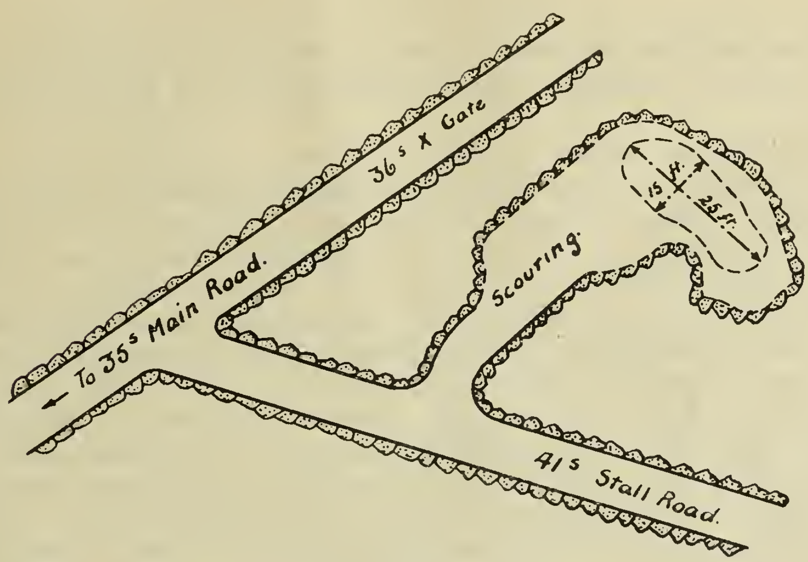


FIG. 42A. FIRE OCCURRING IN THE GOB BY "BREATHING" FROM THE FACE. ENLARGED SKETCH OF SCOURING (Q. 13,447).

A large number of fires were dealt with by this method, but experience proved that it was not always possible to get rapidly to the seat of the fire, and that then the scouring admitted fresh air and often caused what, in the first instance, was only a small heating to become a bad fire, in some cases making the operation a dangerous and lengthy one. The method has therefore been abandoned in favour of building a sand barrier across the waste, of similarly packing up all other wastes between the two adjoining gates, of continuing to work the face forward as quickly as possible, and of building further packs under the new roof in front of those already erected (Figs. 43 and 43A).

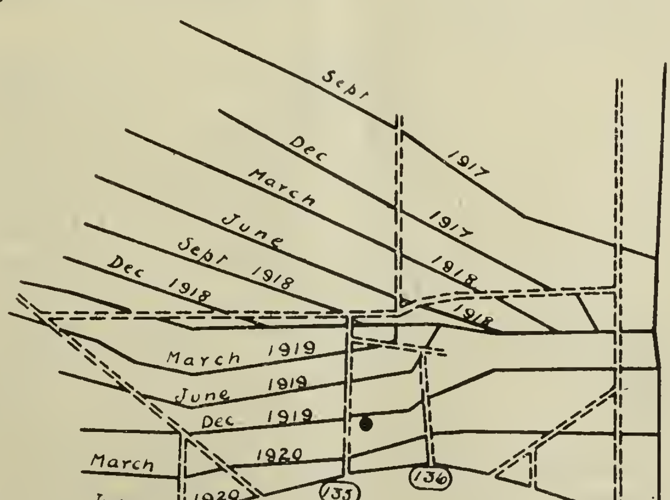


FIG. 43. FIRE OCCURRING IN THE GOB BY "BREATHING" FROM THE FACE (Q. 13,447).

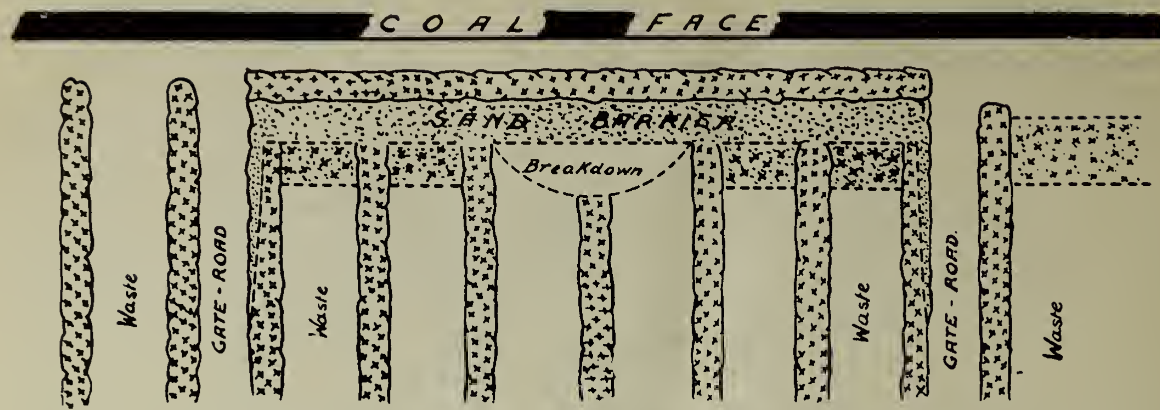


FIG. 43A. FIRES OCCURRING IN THE GOB BY "BREATHING" FROM THE FACE. METHOD OF PACKING (*Q.* 13,447).

Mr. Clive stated that, by these means, provided the face is worked forward continuously, weight is thrown on to the cross-packs and gobs, which are crushed tight.

Fires caused by air pulling through old roads that have not been securely sealed off have been practically eliminated at Bentley Colliery by careful attention to stowing the roads. When ordinary gates are cut off, a solid sand and bind pack is built right across the gate, at the face end, under the Top Soft coal. All timber is drawn from the gate, which is packed solid with bind for a distance of 20 yards at the out-bye end and reinforced with a sand dam in the centre from floor to roof, let well into the sides. The timber in cross-gates is drawn to within 60 yards of each end, the road packed solid for 40 yards, and a sand dam with stone and mortar retaining walls let well into the sides is inserted. The road is packed solid for a further 15 yards, and faced at the main road and return ends with a dam of sand and mortar. This method was stated by Mr. Clive to have been most successful, and no fires had occurred in any gates where the above procedure had been carried out, and there had been only one or two cases of slight gob stink. These latter were dissipated by cutting into the sides to solid ground and building another dam in front (*Q.* 13,477).

5. LANCASHIRE.

The liability to spontaneous combustion in the seams of the Lancashire coalfield is confined to a comparatively small area in the vicinity of Manchester. The late *Mr. J. Gerrard*, H.M. Inspector of Mines for the Manchester and Ireland District, gave the following list of fires or heatings due to spontaneous combustion which had come to his notice in the Manchester district, viz. :—

Foggs Colliery - - -	Doe Seam - - -	6 cases in 11 years.
Agecroft Colliery - - -	Doe Seam - - -	2 cases.
Pendleton Colliery - - -	Four Feet Seam -	2 cases.
Ladyshore Colliery - - -	Trencherbone Seam -	2 cases in 1895. 1 case in 1898. 12 cases in 1898–1906.
,, ,, - - -	Ten Feet Seam - -	1 case in 1903.
,, ,, - - -	Doe Seam - - -	3 cases.
Lord Ellesmere's Collieries -	Trencherbone Seam -	1 case.
Clifton and Kersley Coal Company's Collieries.	Doe Seam - - -	12 cases between 1875 and 1902.

(*Q.* 5959.)

Thus there have been some 42 fires (to Mr. Gerrard's knowledge), ranging over a period of nearly 40 years. It will be seen, therefore, that the conditions in this coalfield are entirely different from those ruling in, say, Staffordshire, where an underground heating is of frequent occurrence.

(A) *Geological Conditions.*

The seams most liable to spontaneous combustion were stated by *Mr. Vincent Bramall*, formerly General Manager to Messrs. Andrew Knowles and Sons, Limited, to be, in descending order, the Shuttle Coal, the Four Feet Coal and the Doe Seam, and these occur at Pendleton as shown below (*Q.* 12,575 to 12,600) :—

Sections of Seams at Pendleton Colliery.

Roof :—A tender blue shale or "metal."

		Ft. ins.		Ft. ins.
	SHUTTLE COAL	2 6	to	3 6
	Dirt (oil shales)	4 0	,,	8 0
	FOUR FEET COAL	3 6	,,	4 6
	Blue "Metal"	Thickness not stated.		
DOE SEAM	INFERIOR COAL	1 0		1 0
	Parting	—		—
	ROOVERS OR BIG TOPS	2 6	to	3 6
	Parting	—		—
	LITTLE TOPS	1 4	to	1 8
	Clayey Shale	0 11	,,	1 8
	LITTLE FOOT AND BIG FOOT BOTTOMS	3 0	,,	3 6
	Thickness of Doe Seam	8 9	,,	11 4

The Shuttle Coal is a clean house coal of a rather friable nature ; the Four Feet Coal is fairly hard and is a good quality steam coal, and the Doe Seam is also of a very good quality.

Mr. T. H. Bailey, of Birmingham, who gave evidence in respect of the Bridgewater Pits of the Earl of Ellesmere, quoted the following section as representative of the Doe Seam.

	Ft. ins.	Ft. ins.		Ft. ins.
Roof :—Metal	—	—		—
CAT COAL	0 11	—		—
Parting	—	—		—
BIG TOPS ("CHITTERY")	1 8	—		—
"Dog"	—	0 2	to	0 3
LITTLE TOPS	1 3	—		—
Clod ("Mouse Tail")	—	0 8	to	1 8
BIG FOOTS	2 0	—		—
Parting	—	—		—
LITTLE FOOTS	1 0	—		—
Clod	—	—		—
Total Thickness	6 10	0 10	to	1 11

In the Lancashire mines heavy faulting is a common characteristic, a factor which, in the opinion of Mr. Gerrard, increases the difficulty of laying out the workings in such a manner as to prevent or reduce the liability to spontaneous combustion (*Q.* 5955). Mr. Bramall held the opinion that the presence of faults was conducive to spontaneous combustion (*Q.* 12,616).

Inasmuch, however, as there is comparative immunity from outbursts of fire-damp, there is little likelihood of an explosion being caused by spontaneous combustion, and no such case had ever come to the notice of Mr. Gerrard. Safety lamps are in general use, more as a precaution than as a necessity (*Q.* 5959).

The inclination of the seams is fairly high, and their depth from the surface is generally very great ; at Pendleton Colliery, for instance, the depth of the shafts is 1,545 ft., and at the face of the workings a depth of 3,760 ft. is reached.

At Bridgewater Collieries, in the Doe Seam, the inferior Top Coal contains finely distributed pyrites, and, according to Mr. Bailey, the management was of opinion that the liability of this coal to fire was assisted by a small quantity of water dripping from the roof (*Q.* 12,242).

The Cat Coal, according to Mr. Bailey, contains some foreign matter of an acid nature (*Q.* 12,247). The dirt between the Shuttle and the Four Feet Coals at

Pendleton Colliery contains a large amount of highly bituminous matter approaching the nature of an oil shale, which Mr. Bramall thought was the source of the trouble at that colliery (*Q.* 12,589). The roofs of the various seams are "tender," a feature which necessitates leaving unworked a portion of the coal for roof protection (*Q.* 12,593). The Shuttle Coal, because of its bad roof, is in many instances not worked (*Q.* 12,575–6).

(B) *Mining Conditions.*

METHODS OF WORKING.—The method of working generally adopted in that portion of Lancashire with which we are dealing is a modification of "Longwall." At various collieries, on account of the surface being thickly covered with buildings and the tender character of the roof, a system of retreating longwall is adopted, in which an area is first cut up into large blocks. The system is termed locally "longwall in bays," and the same method is followed in working all the seams in the district. Two levels, 3 to 4 yards wide, are driven to the boundary; every 200 yards a "bay" (a road some 20 yards in width) is driven to connect them, partly for coal and partly for ventilation. When conditions are suitable and when the far end has been reached, bays are set out in this way and the coal is extracted by retreating longwall in stepped faces.

Mr. Bailey described two methods of working the Doe Seam at Bridgewater Collieries (*see* Fig. 44). In the first or older method, roads were driven to the full rise of the seam 50 to 60 yards apart, with connecting levels 40 to 50 yards apart. The pillars of coal so formed were then removed by bays driven to the rise "on face," three or four being worked at one time. The bays were 14 to 15 yards in width, one several yards in advance of the other, so forming a stepped face. The whole of the coal up to the Big Tops was worked in the face, holing in the clod, but the amount of packing material yielded by the clod was insufficient to pack the goaf completely, and as a result the Big Tops and Cat Coal broke down in the wastes.

In the newer method, a pair of main levels, 30 yards apart, are driven in the seam, and a longwall face is opened out to the rise of the levels, leaving a pillar 30 yards in width on the high side of the main level. The 1 ft. 3 in. of Little Tops is left up over the face timber and only ripped in the drawing roads in order to make height. In consequence of the reduced height of working the clod over the Big Foots gives sufficient material to allow solid packing of the goaf.

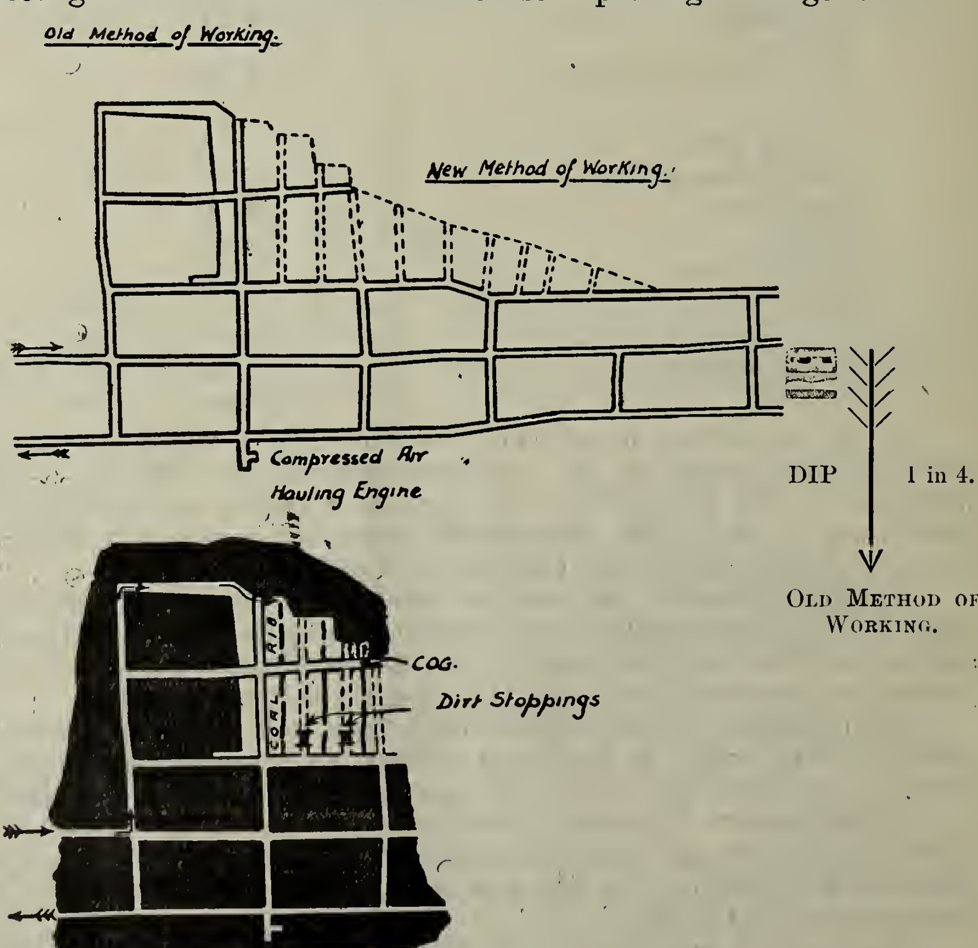


FIG. 44. BRIDGEWATER COLLIERIES—METHODS OF WORKING.

Packs.—The amount of packing done at Pendleton Colliery is dependent on the quantity of material available, and the packs vary in width from 3 to 7 yards. Frequently dirt is brought into the working places from other districts (*Q.* 12,778).

Mr. A. Rushton, the Manager of Abram Colliery, Wigan, in a communication sent to the Committee said, "I am a great believer in substantial packing; it not "only tends to cheapen the maintenance of roads, but better roads can be kept, "and it prevents cavities for gas accumulations and considerably reduces the "risks of underground fires, and if one should occur, you are in a much better and "safer position to deal with it in mines that are well packed than in mines that "are not."

Coal left in Wastes.—Witnesses were unanimously of the opinion that it was the coal left in the wastes that directly contributed to the outbreaks of fire. Thus *Mr. Gerrard*, on being asked if he thought there was anything to be said for the theory that coal left in wastes might cause fires, replied, "All these cases—I am dealing "with my own district—of fires, have been in comparatively thick seams and associated "with inferior coal left" (*Q.* 6151).

Mr. Bailey said that "the Big Tops and Cat Coal broke down in the wastes. "A contributory cause of the breaking up of the roof coal was that nobs of coal "were left in at the carving between the bays for the purpose of holding up "the gob and preventing it running down into the next face following up behind" (*Q.* 12,242).

Mr. Bramall attributed the trouble from fires in the Doe Seam to the slack and small coal left in the waste (*Q.* 12,607). This witness had never found a fire in the solid coal or at the edge of a pillar in the Doe Mine (*Q.* 12,681). As for the Four Feet Seam, where the majority of the fires occurred, he considered that they were due to little pillars of coal left in by the colliers: "In the starting of a bay, they are apt "to leave a little bit of a pillar to steady themselves" (*Q.* 12,739).

Timber.—According to Mr. Bramall, a great deal of timber is left, although it is removed from the waste as far as possible. A large quantity is used in the packs in making corners, but he did not think that the timber so left was conducive to the occurrence of gob-fires (*Q.* 12,762–3).

(C) *Preventive Measures.*

(i) *The Methods in Operation for Preventing Gob-fires.*

The majority of the fires at Pendleton Colliery occur in the worked-out bays, and Mr. Bramall pointed out that these resulted from leakage of air from the newer working places. He considered that the remedy was to be found in fully and effectually packing all disused roads and places (*Q.* 12,783).

(ii) *The Methods in Operation for Dealing with Gob-fires when they Occur.*

The fires occurring in the district are for the most part small and easily dealt with. The symptoms are similar to those of other districts already described. The action taken depends on the extent and position of the fire and the methods adopted at Pendleton are best described in Mr. Bramall's own words. He said, "in the Four Feet "the first symptom noticed, as a rule, is the gob-stink. At Pendleton, where we "have had some large and serious fires, the stink has been noticed one day, and in "the course of a day or two a very serious fire has occurred, large portions of the "pack being much heated. I have tried filling out, but could rarely make any "progress, as, owing to the large amount of coal contained in the wastes, the more "you opened out, the larger the area of the fire. In one or two cases in which "there was a large amount of fire or glowing material, I have found the small fire "extincteurs of great value, as they damped down and extinguished all flame and "glow, and enabled the hot material to be filled out, and damp sand was put in, "and preparations made for suitable stoppings. In dealing with fires, both in the "Doe and Four Feet, I have found the only practical way was to seal them up with "dirt stoppings and sand, afterwards putting in brick walls to the solid. It is a "matter of the greatest importance, where possible, that, while cutting off the air "as much as possible from the fire, a current of fresh air is brought close to the "place, so that if any man is overcome you can at once get him out . . . .

" There are cases where we could not possibly dig them out. It would have " been an impossibility in the Four Foot. A man could only work two or three " hours at digging it out. Immediately you opened out you got the whole thing in a " glow ; and if you put water on it, it of course interfered with the roof and the " whole of the place."

6. FOREST OF DEAN (GLOUCESTERSHIRE).

At least two of the seams found in this district are liable to spontaneous combustion, viz., the Coleford High Delf and the Trenchard. Of the two the Coleford High Delf is the more liable to self-heating.

(A) *Geological Conditions.*

The following are three typical sections of the Coleford High Delf Seam :—

	Ft.	ins.		Ft.	ins.
1. Roof :—Sandstone.					
Smut - - - - -	0	6	to	1	6
Coal - - - - -	4	0	„	5	6
Floor :—Soft dirty fireclay.					
2. Roof :—Sandstone.					
Whitish marly shale - - -	2	0	to	6	0
Top Coal - - - -	0	6	„	0	9
Smut - - - - -	0	6	„	1	6
Coal - - - - -	3	0	„	5	6
Floor :—Soft dirty fireclay.					
3. Roof :—Sandstone.					
Whitish marly shale - - -	1	0	to	3	0
Nodular stone - - - -	1	0	„	3	0
Dark marly shale - - -	1	0	„	3	0
Top Coal - - - - -	0	6	„	0	9
Smut - - - - -	0	6	„	3	0
Coal - - - - -	3	0	„	5	6
Floor :—Soft dirty fireclay.					

It will be seen that although the main roof is sandstone rock, there are throughout the district intervening bands of varying thickness between it and the main seam of coal. The "smut" mentioned in the sections is a carbonaceous shale with shiny fractures, which in no case has been found to exceed 3 feet in thickness. *Mr. J. Morris*, late manager of Lydbrook Colliery, was of the opinion that it is liable to spontaneous combustion, but he was unable to say to what extent (*Q.* 12,823). The sandstone forming the main roof is thick and massive, very jointy, and having numerous sand joints, that is to say, joints that had opened up and had become filled with sand and grit. At Lydbrook Colliery this sandstone rock was about 50 yards in thickness, and no case had been encountered where the rock roof had come right on top of the coal without any intervening dirt. The depth of the coal from the surface was from 50 to 130 yards, and the character and thickness of the several beds of roof material varied, sometimes gradually and sometimes rapidly, between the sections given above. The top coal was very impure, and was left in the gob. Numerous faults were encountered, and Mr. Morris considered them to be fruitful sources of fire for the following reasons: "Unless great care were " taken in filling up the gob next to a fault rough material would roll next to " the fault ; this layer of rough material might form an easy passage for the air " current to percolate through, and the result would be oxidation of the contiguous " fine material and consequent heating. When precautions were taken to ensure " that only fine material was thrown next to faults all fault fires were prevented from " occurring" (*Q.* 12,825).

The coal has a cubical fracture, and sometimes on the facets of the fractures there are yellow films. Whether these are in the nature of pyrites Mr. Morris could not say, but *Mr. Joseph Hale*, Managing Director of the Cinderford Colliery in the same district, said in a written communication to the Chairman, that "the Coleford High " Delf Seam, where the shales between the coal and rock are thick, is often impreg- " nated with iron pyrites and liable to spontaneous combustion."

(B) *Mining Conditions.*

Method of Working.—The method of working the Coleford High Delf Seam is longwall. The seam, at Lydbrook Colliery, lay at an inclination varying from 1 in $3\frac{1}{2}$ to 1 in $7\frac{1}{2}$, the workings being entirely to the rise with the face advancing almost to the full rise. Inclines were driven to the full rise and a pair of levels turned off every 60 yards and driven at a slight rise. Stalls were turned off the levels every 18 yards or so and driven to the full rise as far as the numerous faults would allow (*Q.* 12,824). Heatings and fires occurred only near the face of the workings at a distance varying from 10 to 20 yards therefrom. The face advanced at the rate of $2\frac{1}{2}$ yards per week, and it usually took from four to eight weeks for the gob heat to be sufficient to form a fire. Generally speaking, the gob would be sufficiently compressed in about eight weeks to prevent the occurrence of fire therein. Once the gob had been thoroughly compressed it did not heat up unless something were done to allow the freer percolation of air through it. The fires, commonly, were not deep seated; as a rule they occurred at a distance of about 6 feet from the sides of the roads, the exceptions being cases where the gob had not been fully packed. The packs were built with smut, but it is probable that a certain quantity of dirty coal was included (*Q.* 12,831).

Mr. Morris had a special staff whose duty it was to draw out the timber, but even then he considered that one-third to one-half would be left; he did not think, however, that the timber at that colliery had any very great bearing on the question of gob fires, and he had found a fire where there had been no timber left in the vicinity (*Q.* 12,833–34).

The widths of the packs varied considerably, but in most cases they were filled quite solid; in other cases where the workings were practically under the main rock there would be about 4 yards of pack next to the road, with the distance between filled with chequered dirt cogs. It was mostly where the gobs were filled solid, and not where there were wastes, that fires were found, for which Mr. Morris gave the following explanation: "Where it came down near the top coal we had breathings of " black damp issuing from the rock, and I think most of the wastes were filled with " black damp after we passed on. In fact, the roof everywhere breathed black damp, " and the rock roof especially. Sometimes you would get blowers of black damp " that would put out a candle." There was no explosive gas, however, it being a well known fact that, so far, marsh gas has never been detected in the Forest of Dean.

It will be observed that the Coleford High Delf Seam is not a thick coal, but unfortunately the Top Coal, which varies from 6 ins. to 9 ins. in thickness, is of a very inferior quality, and it would appear to be the custom to leave this coal in the gob.

The question of pillars is not of great concern in this district as the coal is worked longwall at a comparatively shallow depth, but Mr. Morris gave one instance of a pillar of coal in Lydbrook Colliery having taken fire. It was an old pillar at the side of the road; the pillar was being worked back, and this threw a greater crush on that portion remaining. As a result a fire ensued in the cracks in the coal about 5 ft. from the edge of the pillar.

Leakage of Air across Gateways through Packs and Waste.—Mr. Morris was fully convinced of the necessity of preventing short-circuiting of air through the packs if fires were to be avoided. In fact, he attributed the majority of the fires at Lydbrook Colliery to this cause, and quoted a case where the seam had been worked and the gob had been properly packed between the intake and the return air-way. The coal had been worked out for about six months when it was decided to drive a road underneath the gob in order to prove a fault. This had the effect of easing the pressure on the gob above, with resultant leakage of air and outbreak of fire (*Q.* 12,826). He also said: "As a rule fires occur only in places where the ventilating current " tended to short-circuit through the gob material; this might be caused by—

"1. Irregular subsidence of the roof due to its varying strength or to the " presence of faults. This might delay the due compression of the gob, " or result in irregular compression. The ventilating current might " percolate through the more porous portions of the gob, with the result " that oxidation and heating would follow.

"2. The tendency of the air current to short-circuit through the gob material, " due to the method of working that particular place, or to the presence " of faults in the roof, faults or rolls on the face.

"3. Delay in the compression of the gob in the case of a new district being " opened out, or in the case of opening out behind some barren portion of " the seam." (*Q.* 12,824.)

He further stated, in regard to subsidence and percolation of air, that when the roof did break down it might give a vent to any fire that had been incipient in the waste, and that when the roof continued to subside it would eventually compress the gob sufficiently to put out the fire (*Q.* 12,850).

(C) *Preventive Measures.*

(i) *The Methods in Operation for Preventing Gob-fires.*

Mr. Morris put forward the following as the precautions which in his opinion should be taken for the prevention of gob-fires. These, stated briefly, were to the following effect:—

(i) So to lay out the workings that the ventilating current would pass along the face direct to the return, so obviating the erection of brattice sheets in the stall roads.

(ii) The rapid removal of all falls occurring in the coal face.

(iii) The prohibition of rough gob material being left next to faults, or leaving pieces of coal unworked.

(iv) The placing of brattice sheets as far from the corner of the gob as possible to avoid forcing the air through the corner of the gob.

(v) The division of the workings into as many separate ventilating districts as possible. Increase in air-current in a district to be secured by enlarging the air-ways rather than by increasing the ventilating pressure. The ventilating pressure to be kept as low as possible with due regard to efficiency of ventilation of the mine.

(vi) The provision of portable fire-extinguishers.

(vii) Provision to be made for the quick erection of substantially bricked-in doors both in the intake and return in every district liable to fires, so that a district can then be quickly sealed off. The brick work to be well plastered.

(ii) *Methods in Operation for Dealing with Gob-fires when they Occur.*

The first symptom of the presence of a heating, or of an incipient fire noted by Mr. Morris, was the sweating of the timber and roof in the vicinity. This was followed in due course by the issue of watery vapour, drying of the gob walls, and issue of gob stink (*Q.* 12,827). " Generally speaking, nothing was done in the case " of heatings observed except constant examination, until gob stink could be " detected; then the fire was dug out, cooled and filled out. Possibly not 10 per " cent. of the heatings observed resulted in fire. In most cases the subsidence of the " roof would be sufficient to prevent further percolation of air, and the heating would " subside. Again, only a small proportion of the fires would result in flame. They " would generally be detected and dealt with before the glowing material would be " more than sufficient to fill one bucket. We found portable fire-extinguishers " extremely useful in dealing with fires" (*Q.* 12,828).

In one case a fall had taken place, causing the air to short-circuit and percolate to the gob, the usual preliminary signs of fire were not observed until there was a strong emission of smoke; the fire, which was about 10 yards from the side of the road, developed flame before filling out could be resorted to; the district was sealed off and left for a period of six days. On re-opening the district the fire broke out again in a few hours, and the district was again sealed off and left for a fortnight; again on re-entry the fire broke out and again the district was sealed off for the third time and left for a fortnight. The fire was only finally overcome by filling up the roads leading to and from it (*Q.* 12,850).

Mr. Morris gave the following method of dealing with fires occurring in pillars of coal left for support, viz.:—A fire had taken place in the cracks produced in a pillar by crushing, and it was put out by boring a number of holes into the cracks and forcing in water which had been made thick with clay. He used for this purpose a

Burnside Rod without the frame, packing it tight with some spun yarn in the bore-hole so that the rod could be easily drawn out. He was unable to state what proportion of water and clay was used, which was limited only by the capacity of the pump to pass the mixture.

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7. FIFESHIRE.

The coalfield of Fifeshire, although small in comparison with many of the English fields, is one of great importance to the Scottish coal trade, both by reason of its geographical situation and of the variety and number of its coal seams.

Mining in Fifeshire has been actively prosecuted for many years and mention has already been made in this Report of a valuable contribution by an Edinburgh mining engineer to the literature of spontaneous combustion so long ago as the early part of the nineteenth century. (*See* page 8.)

Since that time trouble has been continuously experienced both from the spontaneous combustion of coal underground and the self-heating of heaps of coal on the surface. With regard to the latter phase of the question, *Mr. H. Rowan*, Agent to the Fife Coal Company (who appeared before us), said :—

> "Mining Engineers in Fife have experienced considerable trouble from the firing of coal-bings, and their experience has been very similar to that recorded by Fayol. Screened coal, or nuts, have never fired, but duff, small coal, and unscreened coal have fired and heated frequently. One important difference, however, has been experienced ; in a wet season there has been a greater number of fires of this class than in seasons of moderate rainfall."

(A) *Geological Conditions.*

Geologically, Fifeshire is of interest because within its boundaries are found the four geological horizons into which the coal-bearing strata of Scotland are divided, viz. :—

1. The Upper Carboniferous Series (*i.e.*, "True" Coal Measures, corresponding to the Middle Coal Measures of England).
2. The Millstone Grit Series.
3. The Lower Carboniferous Series (the "Limestone Coal Measures.")
4. The Calciferous Sandstone Series.

The coalfield extends for some 30 miles along the northern shore of the Firth of Forth and has a breadth northwards of between five and six miles. Of this area, the Dysart, Wemyss and Leven coalfield occupies a triangular-shaped area some 20 square miles in extent, with a base extending a distance of $8\frac{1}{2}$ miles along the shore from Dysart to Leven in a north-easterly direction. The western side of the triangle extends along the outcrop of the Dysart Lower or Seven-Feet Seam (the lowest seam of the series) from Dysart to a point about one mile east of Markinch. The northern side of the triangle extends from Markinch to a point on the shore about $1\frac{1}{2}$ miles north-east of the mouth of the River Leven.

The seams now being worked in the Wemyss area are confined to Series 1, *i.e.*, the True Coal Measures, and of the 12 workable seams mentioned by *Mr. Richard Kirkby*, Agent and General Works Manager of the Wemyss Coal Company (in his evidence before us), the two thickest and most important, both from the commercial point of view and from that of spontaneous combustion, are the Chemiss and Dysart Main Seams. The existence within this area of all the coals of Series 3, or the Limestone Coal Measures, has been proved by boring, and these are found to be exactly as worked in the West Fifeshire Coalfield.

The West Fife area is of greater extent than the Wemyss area, stretching as it does from Bowhill on the east to Saline and Oakley on the west, where the main Fifeshire coalfield merges into that of Clackmannanshire. Here the rocks composing the series have been faulted into basins, of which the most prominent are those of Dunfermline, Kelty, Lassodie, and Lochgelly. Numerous seams of coal of workable thickness occur in this series, but, almost without exception, underground fires have been confined to the Lochgelly Splint Coal, which is found over a considerable part of the coalfield, but is inconsistent as to character and thickness. The coal measures of Fifeshire have been subjected to much faulting and to wide intrusions of volcanic rocks which latter have had the effect of converting some of the bituminous coals into an anthracite or semi-anthracite. Most of the faults in the Wemyss area trend in an east and west direction and have considerable throws mainly to the south, and the most northerly

has the effect of cutting out the coals entirely. Mr. Kirkby said of the large dislocations generally that they "have no influence on the coal seams as regards their liability "to spontaneous combustion." The evidence from Fifeshire as to the adverse effect of small faults was similar, however, to that from other districts, and Mr. Kirkby quoted cases of fires arising from coarse inferior coal having been left in the vicinity of faults with throws of from one to three feet.

In Series 3 of the western area the faulting has a prevailing trend to the west-north-west, also throwing towards the south, the northern boundary fault being a prolongation of that mentioned previously. An anticline, the axis of which runs in a south-westerly direction, occurs on the western side of the Wemyss area causing a rapid change to take place in the normal dip of the seams.

The rate of dip of the seams varies considerably, and in the Wemyss portion of the coalfield inclinations of from 1 in 3 to 1 in 12 are met with. The normal direction of the dip is towards the south-east, and the same seams reappear on the southern shore of the Firth. By reason of faults and anticline, the direction of the inclination is by no means regular. Further west the coals in Series 3 are comparatively poor at the shore, but rapidly improve in quality and thickness to the north, until the centre of the field is reached at Lochgelly. The general direction of the dip from Dunfermline is northerly, but there are areas where the inclination is quite inconsistent with the general direction. The seams get thinner as they approach the western boundary of the field, and in West Fife also the dip varies from 1 in 2 to 1 in 10.

The depth of those seams in the Wemyss coalfield that are liable to spontaneous combustion varies considerably, but is fairly consistent in the collieries along the seaboard. At Wemyss, the southern end of the coalfield, the depth of the Chemiss seam from the surface is 800 feet, and that of the Dysart Main Coal 1,600 feet. Towards the north at Leven the depth of the Chemiss from the surface is 900 feet, and at Wellesley near Leven the Dysart Main Coal is 720 feet below the Chemiss Seam or a depth from the surface of some 1,600 feet.

The depth from the surface of the Lochgelly Splint Seam varies from the outcrop down to over 1,300 feet, and the maximum depth reached by the shafts of the Fife Coal Company is at Cowdenbeath No. 10 Pit, where the coal lies at a depth of 1,380 feet from the surface.

The depth of coal seams has a direct bearing on the question of spontaneous combustion, but Mr. Rowan could not agree with the theory held by Dr. Harger that "Hot mines are practically the only ones in which gob fires occur."* He pointed out that the mines in West Fife could not be termed hot, and that serious gob fires had occurred where the normal temperature did not exceed 60° to 62° Fahr.

The thickness of the three seams with which we are dealing more particularly varies greatly both as regards the actual thickness of the coal and the bands of dirt. These variations are best illustrated by the sections reproduced below.

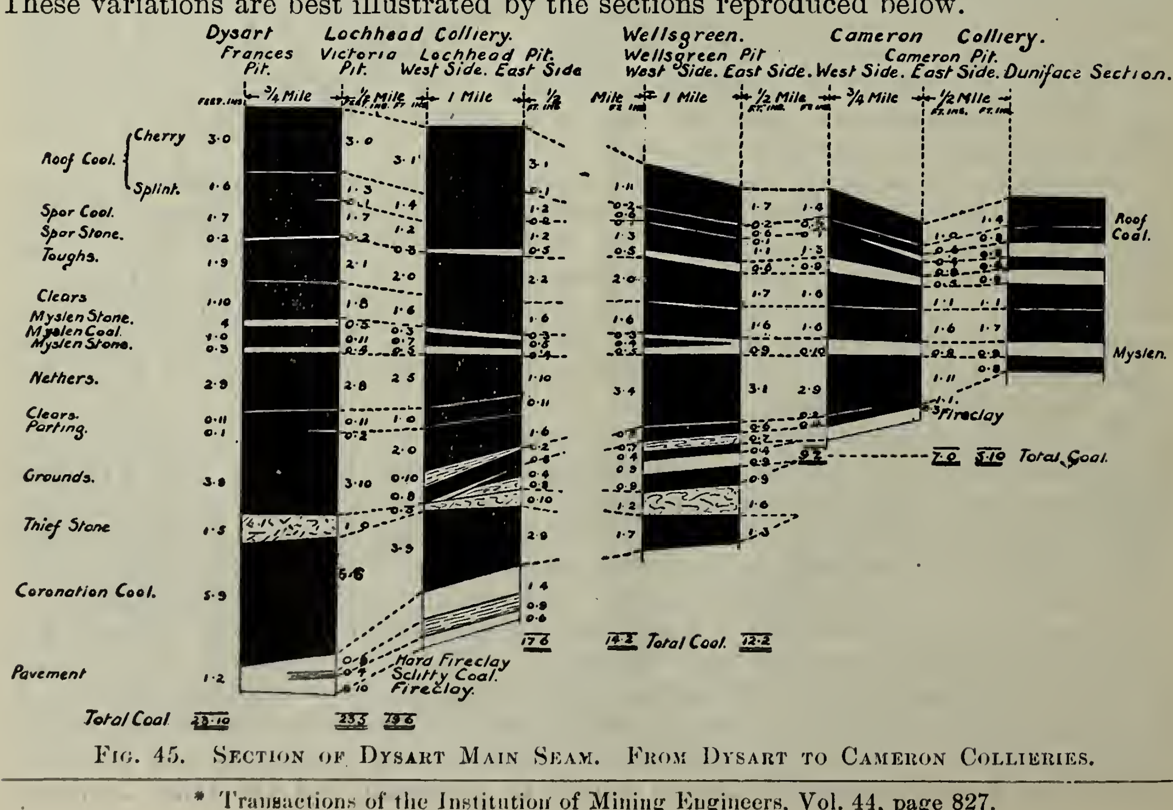

FIG. 45. SECTION OF DYSART MAIN SEAM. FROM DYSART TO CAMERON COLLIERIES.

* Transactions of the Institution of Mining Engineers, Vol. 44, page 827.

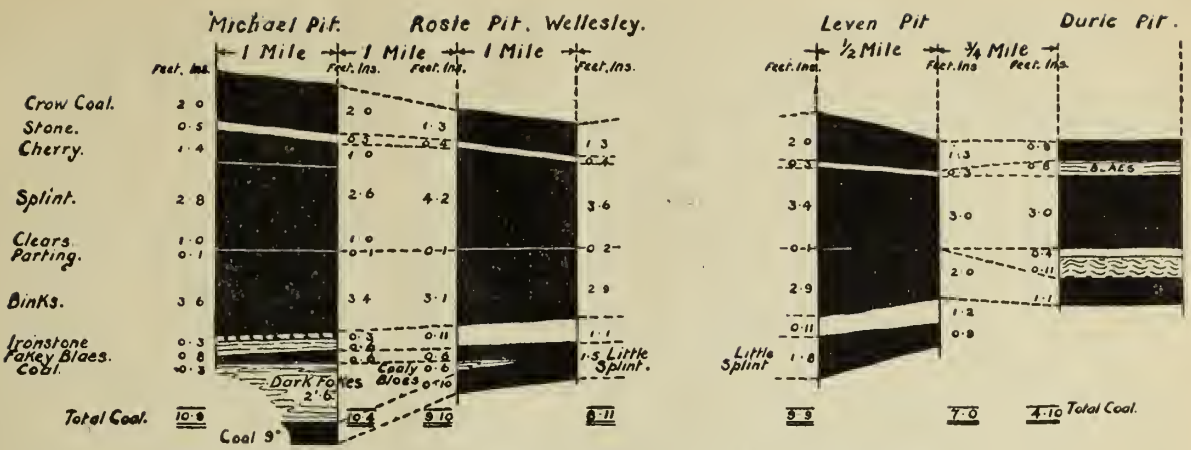

FIG. 46. SECTION OF CHEMISS SEAM. FROM MICHAEL TO DURIE COLLIERIES.

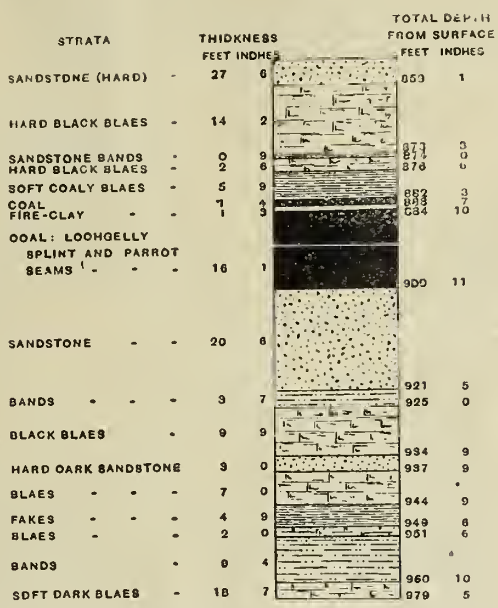

FIG. 47. SECTION OF STRATA. LOCHGELLY SPLINT SEAM.

In the case of the Lochgelly Splint Coal there are two distinct seams (*see* Fig. 47), the upper portion being known as the "Lochgelly Splint" and the lower as the "Lochgelly Parrot." The two seams are found close together over a considerable area and they vary in thickness from 8 to 14 feet. In other parts of the West Fife Coalfield the two seams are separated by bands of strata varying from a few inches in thickness to several fathoms. The roof of the Lochgelly Splint Seam is of a tender nature and composed of "Blaes" or argillaceous shale; directly below this occurs an inferior coal termed in Scotland "foul" coal, which is economically unworkable and is allowed to fall in the gob. Mr. Rowan gave it as his opinion that the gob fires in his district were due to this foul coal breaking down in the gob behind the working faces. As shown in Fig. 47, the floor is usually sandstone, but in some districts a band of fireclay varying in thickness from 1 inch to 4 feet is found.

In the eastern portion of the coalfield occurrences of spontaneous combustion have been, so far, confined to the two seams already mentioned, *i.e.*, the Chemiss and Dysart Main, although Mr. Kirkby stated that heatings had occurred in the lowest seam of the series, viz., the Dysart Lower or Seven-Feet Seam, and expressed the opinion that the liability of this seam to fire might greatly increase on further development.

At Michael Colliery, on the seashore about 3 miles from the southern extremity of the field, the thickness of the Chemiss seam, exclusive of partings, is 10 feet 6 inches, while in the Durie workings (now abandoned) some 5 miles north-east, it had diminished to 4 feet 10 inches. The roof of this seam was stated by Mr. Kirkby to be almost invariably composed of "blaes" extending to a height of from 3 to 30 feet; above this is a sandstone post. Occasionally the shale or blaes thins out, and the sandstone rests on the coal. Questioned as to the greater liability to spontaneous combustion of the coal when this happened, Mr. Kirkby said that no difference had been observed. The floor of the seam is fireclay.

The Dysart Main is a thick seam, but here again the thickness varies to an extraordinary degree. In the Frances Pit at Dysart its total thickness, including partings, is 26 feet, the thickness of coal (all workable) being 24 feet, while at Duniface, near Windygates, the total thickness of the seam is 8 feet, with 5 feet 10 inches of coal of which 4 feet 6 inches are workable.

There is a great difference in liability to spontaneous combustion in the case of the Dysart Main Seam in the various parts of the coalfield, and Mr. Kirkby attributed the comparative immunity of the coal in the north-east portion to the fact that here it thins out to a considerable extent. At Cameron Colliery, for example, the average section, including partings, measures only some 7 feet in thickness, and no fires from the self-heating of the coal have been experienced during 30 years. On the other hand Mr. Rowan's experience is somewhat different. Fires frequently occur in the upper workings of the Lochgelly Splint Seam where the thickness of coal does not exceed 5 feet, and he could not be sure that outbreaks might not take place in seams even thinner. The roof of this seam is invariably blaes attaining a thickness of 8 to 15 feet above the coal. The pavement is a fireclay mixed with bands of ironstone balls and inferior coal, and varying as to hardness.

Lochhead Colliery.—Dysart Main Coal.

		Ft. ins.	Ft. ins.	
Post:—Sandstone.				
Roof	Grey Blaes	—	4 9	
	Dark Blaes	—	10 0	
	Ironstone	—	0 3	
	Black Soft Blaes	—	1 9	
	CHERRY COAL	3 1	—	
THIRD WORKING	Parting	—	—	
	SPLINT COAL	1 2	—	Rather ashy; usually left underground.
	Stone	—	0 2	
	SPAR COAL	1 2	—	Good bright coal.
	Spar Stone	—	0 5	
	TOUGHS	2 2	—	A dull coal closely laminated with "Mother of Coal." Good steam coal.
	Parting	—	—	
	CLEARS	1 6	—	Bright cherry coal, good, but quick burning house coal.
SECOND WORKING	MYSLEN: Stone	—	0 3	
	MYSLEN: COAL	0 5	—	
	MYSLEN: Stone	—	0 4	
	NETHERS	1 10	—	Good hard splint coal.
	Parting	—	—	
	CLEARS	0 11	—	
	Parting	—	—	
	GROUNDS	1 6	—	Brightish hard coal.
	Stone	—	0 2	
	COAL	0 8	—	Clean coal.
	Parting	—	—	
	COAL	0 4	—	
	Stone	—	0 8	
FIRST WORKING	Thief Stone	—	0 10	Hard sandy fireclay.
	CORONATION COAL	2 9	—	
	Totals	17 6	2 10	
	Total Thickness with partings		20 4	

Pavement: Fireclay.

Victoria Colliery.—Dysart Main Coal.

Roof :—Blaes.

		Ft. ins.	Ft. ins.
Fourth Working	Cherry Coal	3 0	—
	Parting	—	—
	Splint Coal	1 6	—
	Stone	—	0 1
	Spar Coal	1 7	—
	Spar Stone	—	0 2
	Toughs	2 1	—
Third Working	Parting	—	—
	Clears	1 8	—
	Myslen: Stone	—	0 5
	Myslen: Coal	0 11	—
	Myslen: Stone	—	0 4
	Nethers	2 8	—
	Parting	—	—
Second Working	Clears	1 0	—
	Parting	—	—
	Grounds	3 10	—
	Thief Stone	—	1 0
First Working, Coronation Coal		5 6	—
	Totals	23 9	2 0
	Total Thickness with partings		25 9

Pavement :—Fireclay.

The description of the various " leaves " of the seam is as shown on the section taken from Lochhead Colliery.

Earlseat Colliery.—Average Section of Dysart Main Coal.

Blaes :—3 ft. to 12 ft.

		Ft. ins.	Ft. ins.
Cherry Coal		1 0	—
Coal		1 0	—
Splint Coal		1 3	—
Second Working, 5 ft. 6 ins.	Stone	—	0 2
	Spar Coal	1 6	—
	Parting	—	0 1
	Toughs	2 0	—
	Clears	1 9	—
First Working, 6 ft. 1 in.	Myslen: Stone	—	0 2
	Myslen: Coal	0 3	—
	Myslen: Stone	—	0 2
	Nethers Coal	1 9	—
	Grounds Coal	2 3	—
	Daugh (Sclitty)	—	1 6
Coal		0 10	—
Thief Stone		—	1 4
Coal		1 11	—
Hard Stone		—	1 6
Totals		15 6	4 11
Total Thickness with partings		20 5	

Wellesley Colliery.—Dysart Main Coal.

Sandstone :—

	Ft. ins.	Ft. ins.	Ft. ins.
Fakey Blaes	6 0	—	—
Blaes	3 2	—	—
COAL		2 1	—
Stone		—	0 6
COAL		0 6	—
SECOND WORKING — Stone		—	0 2
SECOND WORKING — SPAR COAL		1 0	—
SECOND WORKING — Stone		—	0 6
SECOND WORKING — COAL		3 2	—
FIRST WORKING — Myslen Stone		—	1 0
FIRST WORKING — COAL		2 10	—
FIRST WORKING — Stone		—	0 1
FIRST WORKING — COAL		0 10	—
Soft Fireclay		—	0 4
Hard Fireclay and Balls		—	0 10
Soft Fireclay		—	0 8
Sclitty Coal		—	0 7
Fireclay		—	0 7
Sclitty Coal		—	0 5
Fireclay		—	0 3
Sclitty Coal		—	0 4
Soft Fireclay		—	1 2
Sclitty Coal		—	0 3
Totals		10 5	7 8
Total Thickness with partings		18 1	

Lumphinnans No. 1 Pit.—Lochgelly Splint Coal.

Roof :—Fakes (Arenaceous Shale).

	Ft. ins.	Ft. ins.
"WILD" COAL	0 10	—
Fireclay	—	0 6
CHERRY COAL	1 0	—
SPLINT COAL	0 4	—
"Dugger"	—	0 2
HARD SPLINT COAL	4 2	—
CHERRY COAL	2 4	—
Fireclay	—	1 9
"FREE" COAL	1 4	—
"Dugger"	—	0 1
COAL	1 6	—
"Dugger"	—	0 1
PARROT COAL	1 0	—
COAL	0 6	—
Totals	13 0	2 7
Total Thickness with partings	15 7	

Floor - - - - - - - - Fireclay.

In common with the majority of the coals of Scotland, the Fifeshire seams are to a great extent bituminous, but this term cannot with complete truth be applied to the three seams with which we are dealing. For example, the Lochgelly Splint Coal varies in the two parts of the seam as to its bituminous characteristics as well as chemical

composition. The quality and characteristics of the Chemiss Seam also vary. Questioned as to the presence of pyrites in the coal and as to its association with spontaneous combustion, Mr. Kirkby said that pyrites did occur in the thick portion of the Chemiss Seam at Leven Colliery, but he did not consider that its presence affected the coal, and, as a matter of fact, no fire had ever been experienced in that particular sector.

The following analyses were furnished by Mr. Kirkby:—

ANALYSES OF FIFESHIRE COALS.

Seam.	Volatile Matter.				Coke.			
	Gas Tar, &c.	Sulphur.	Moisture.	Total.	Fixed Carbon.	Sulphur.	Ash.	Total.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Dysart Main (Lochhead):—								
"Spar," "Toughs" and "Clears"	29·74	0·18	12·28	42·20	53·45	0·25	4·10	57·80
"Nethers" and "Grounds" -	28·51	0·21	12·73	41·45	54·76	0·29	3·50	58·55
"Coronation" - - -	34·68	0·65	12·72	48·05	45·80	0·70	5·45	51·95
Dysart Main (Wellsgreen):—								
"Spar," "Toughs" and "Clears"	29·97	0·27	13·76	44·00	50·95	0·35	4·70	56·00
"Nethers" and "Grounds" -	31·64	0·54	14·78	46·96	46·94	0·60	5·50	53·04
Chemiss (Michael):—								
Splint Leaf - - - -	36·26	0·28	13·16	49·70	47·06	0·29	2·95	50·30
Binks - - - - -	36·07	0·52	13·06	49·65	45·37	0·53	4·45	50·35
Barncraig:—								
Splint - - - - -	33·90	0·21	12·34	46·45	50·71	0·24	2·60	53·55
Clear Coal - - - -	34·68	0·27	13·40	48·35	48·35	0·28	2·75	51·65

ANALYSIS OF "CLEARS" PORTION OF DYSART MAIN SEAM.

	Per cent.
Carbon - - - - - - -	78·18
Hydrogen - - - - - -	5·18
Oxygen - - - - - - -	14·62
Nitrogen - - - - - - -	0·81
Sulphur - - - - - - -	1·21
	C.c. per gram.
Total gas evolved - - - - - -	283

ANALYSES OF BLAES AND CROW COAL ON TOP OF DYSART MAIN SEAM.

	Blaes (Black Shale).	Crow Coal.
	Per cent.	Per cent.
Gas, tar, &c. - - - - -	18·26	30·47
Fixed carbon - - - - -	10·53	43·20
Sulphur - - - - -	2·33	2·61
Ash - - - - - -	64·30	8·65
Water - - - - -	4·58	15·07
Water in air-dried sample - - -	2·64	—
Coke - - - - - -	76·61	—

(B) *Mining Conditions.*

METHODS OF WORKING.—Both the longwall and the pillar and stall (or, as it is termed in Scotland, "Stoop-and-Room") methods of working are in operation in the Fifeshire coalfield, and the method is dependent mainly on the thickness of the seam and the intervention of strata dividing the coal into two or more sections.

In the Western area, where the two sections of the Lochgelly Splint Seam are close together, and where, as a result, there is little or no stowage material available, the pillar and stall system is universally applied. In other parts of the district the two seams are separated, as has been stated, by bands varying from a few inches up to several fathoms in thickness, and where these bands are thick either longwall or a modified system of longwall is adopted.

Mr. Rowan fully described the difficulties that had been met with in the past and the methods adopted to obviate or minimise the risk from underground fires. He said : "During the last 50 years various methods have been adopted for working the "Lochgelly Splint Seam in the Fife district. The earliest method seems to have been "to work by stoop-and-room, splitting up the stoops until 60 to 70 per cent. of the "coal had been worked out, and thereafter abandoning the whole section" (Fig. 48).

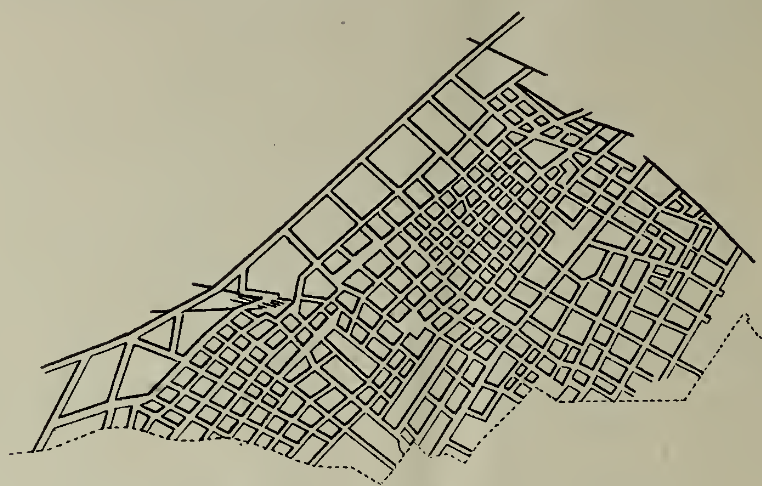

FIG. 48. LOCHGELLY SPLINT SEAM. PLAN SHOWING EARLIEST METHOD OF WORKING BY STOOP-AND-ROOM SYSTEM (PILLAR AND STALL).

"Attempts have been made in different parts of the field to recover some of these small stoops, but with very little success, as it was found that shortly after operations were begun heating took place, fire afterwards broke out, and the place had to be sealed off. The apparent cause of the fire in these cases was the grinding of the subsiding strata upon the small pillars.

"At a later period it was found that the system of working was to drive out from the side of a main road, for a distance of 200 to 300 feet, two parallel places 10 feet wide by 5 in height, to open out a face of about 100 feet, and to work both seams back to within 30 feet of the main road, building off the two entrances, and thus sealing off the pocket (Fig. 49). While fires were less frequent by this method a great amount of coal was lost in the barriers left all round the small pockets.

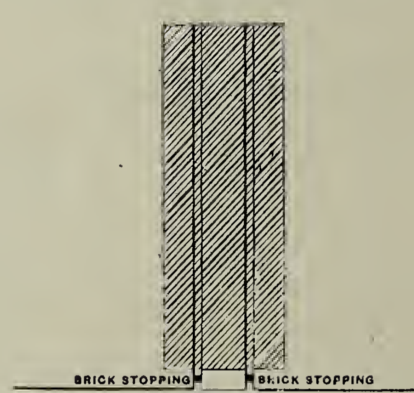

FIG. 49. LOCHGELLY SPLINT COAL. PLAN SHOWING LATER METHOD OF WORKING IN SMALL PANELS, WITH ENTRANCES FROM MAIN ROAD SEALED WITH BRICK STOPPING.

"Later still, it was thought to improve upon this system by forming much larger pockets or panels. A number of places were driven out from a main road as before, but, as soon as they were driven to a sufficient distance to form a barrier on the main road, they were all connected and worked forward by longwall, carrying the upper seam on wooden pillars and small coal (Fig. 50). This working was carried forward for a considerable distance, when the upper seam was opened out and worked back towards the barrier which had been left against the main road ; but the working of the upper seam had not proceeded far before fire began to show, and the openings into the panel had to be built up and the section abandoned. Numerous attempts have been made to recover some of the coal in these panels, but with very little success, as fire broke out shortly after the working had been commenced.

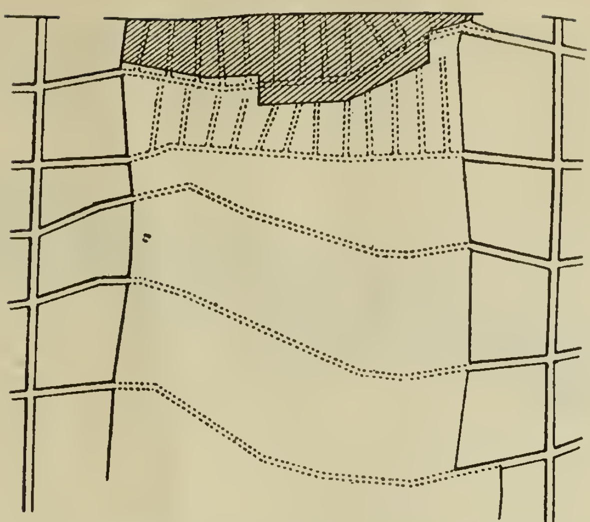

Fig. 50. Lochgelly Splint Seam. Plan showing Modern Method of Panel Working by Longwall.

"Still another system of working was tried for this seam. A large block was laid off by stoop-and-room, the rooms being 10 feet wide by 5 feet high, and the stoops 450 by 300 feet, with the long side of the stoop parallel to the dip of the seam (Fig. 51). When this stoop-and-room working had been carried forward to a natural boundary, the upper seam was opened out; the work was then begun on the retreating system, and all the upper seam worked out along with the stoops which had been formed in the lower seam. This work on the retreating system was continued for two years before any sign of heating was found; but, shortly after this heating was discovered in the waste, fire broke out, and the whole section had to be built off."

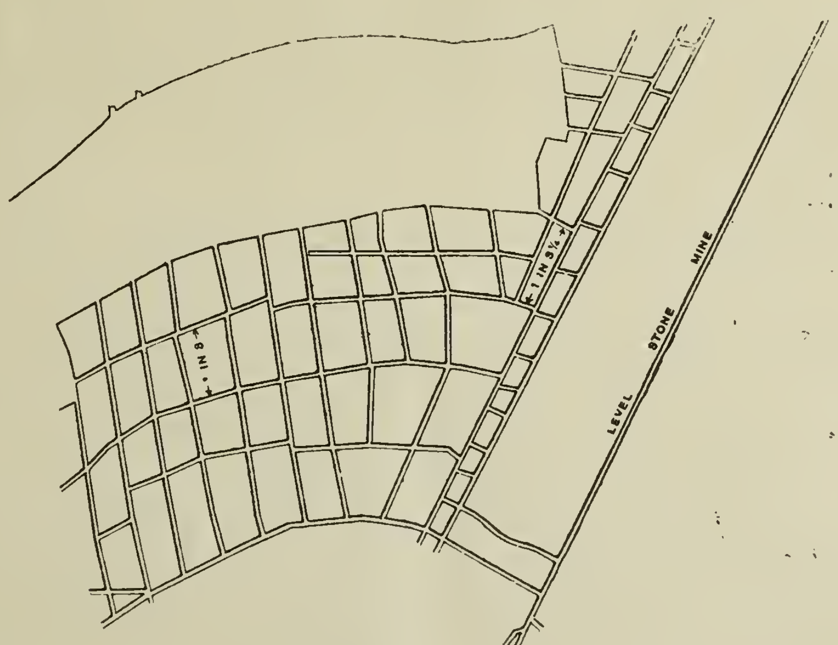

Fig. 51. Lochgelly Splint Seam. Plan showing Method of Working the Lower Seam by Pillar and Stall, and the Top Seam and Pillars left in the Lower Seam by Retreating Longwall.

Mr. Rowan expressed the opinion that the heating of coal which occasionally occurs under the last-named system took place in the small ribs of coal left to protect the men when opening out fallen-in working places. He was also of opinion that most of the fires occurring in the Lochgelly Splint Seam are, to some extent at least, caused by the subsiding strata grinding upon small pillars of coal or upon heaps of

small coal left in the wastes. He thought if this difficulty could be overcome fires would not be so frequent. He expressed the view that with such a roof as that overlying the upper seam (*see* Fig. 47) difficulty would always be experienced in keeping open a longwall face or in getting out all the coal.

After fair trial had been given to the various methods just described, the conclusion was reached that none of them was suitable, and the system of working was once more altered. Under the latest method to be adopted the lower seam is worked by longwall, the waste between the roads is packed solid with material got from pavement ripping or from other sources, and the intention is that when subsidence due to this first working has completely ceased, longwall will be commenced in the upper seam ripping the roof and solidly stowing the waste. Mr. Rowan is hopeful that a diminution in fires will result from this new practice.

In the Wemyss area the original practice was to work the Dysart Main Seam by the pillar and stall method, and this system has persisted in many Dysart collieries to the present day. As new collieries were opened up, however, and as the seam was found of varying thickness, the longwall method was gradually adopted. Panel working is favoured to a great extent, and the seam is removed in a series of "lifts," in number according to its thickness. Thus, at Victoria Colliery there are four lifts or distinct workings, at Lochhead there are three, and at Earlseat and Wellesley Collieries only two. Where the operation is in four lifts the following procedure is followed:—The bottom or Coronation leaf is first worked to the boundary of a panel, the size of which has been pre-determined, the waste being stowed with the dirt obtained from the holing. The holing is done both by hand and machine, the former yielding the greater amount of stowage material, and the waste being much more fully packed than when machines are used. The second leaf, having the Nethers Coal as a roof, is also worked forward and holing is done in the parting and in the roof coal and the Thief Stone on the floor is lifted and stowed. The third leaf is holed in the stowage of the second working, care being taken to lift as much of this old stowage as possible in order to increase the amount of material available for stowing the third working. The fourth leaf is worked back, and the present practice is to take down all the coal up to the blaes roof, packing the splint coal in the waste. It is when retreating in the final working that trouble from spontaneous firing of the coal is experienced and, as *Mr. Kirkby* pointed out, the roads behind the retreating face are not maintained, and difficulty in locating outbreaks is experienced.

Where two lifts only are required to remove the entire section of coal as at Earlseat, Wellesley, Wellsgreen, and Muiredge Collieries, a similar method is practised except that it is not retreating. As will be seen from Fig. 45, the diminution in thickness of the seam takes place chiefly in the lower leaves. At Wellsgreen Colliery the first or bottom working extends from the top of the four inches of coal to the top of the Myslen Stone. This coal is about 4 feet thick, and is the representative of the "Nethers," "Clears," and "Grounds," which are 6 feet thick in Lochhead Colliery and 7¼ feet in Victoria Colliery. The holing is made in the bottom, and the material got in this operation and from the Myslen Stone is sufficient to stow the waste of the first working. The second working is carried out in the Spar Coal, Duffs and Clears about 4 feet 8 inches in section. For stowage 6 to 9 inches of the floor is lifted and this, together with the Spar Stone, yields 12 to 14 inches available for stowing the second working. The wastes of this working are not so thoroughly packed as the lower, but Mr. Kirkby stated that for a considerable period no fires had been encountered in Wellsgreen Colliery. On being asked to what he attributed the comparative freedom from fire, he replied: "The pavement " is soft and the waste did not stand for long before it all heaved up and closed it. " The waste is better packed than it is in Lochhead Colliery." He agreed that owing to the better packing material available, softer floor and fairly even settlement of the roof, the packs became so tight as to prohibit leakage of air into the wastes.

The variation in the thickness of the Chemiss Seam has already been remarked on (*see* Fig. 46), and the coal is removed in one or two operations according to its thickness in a manner similar to that practised in working the Dysart Main Seam. The top leaf, or Crow Coal, is left up over the whole field and in some cases, especially in the north, the bottom leaf, or Binks Coal, is coarse and its value lessened by reason of the presence of iron pyrites. In such cases this bottom coal is

also left and the middle portion, termed the Splint Coal, alone is worked. Fig. 52 is a section illustrating such a case. The Binks Coal was here taken up in the roadways to make height, and, as usual, the Crow or Roof Coal was left intact.

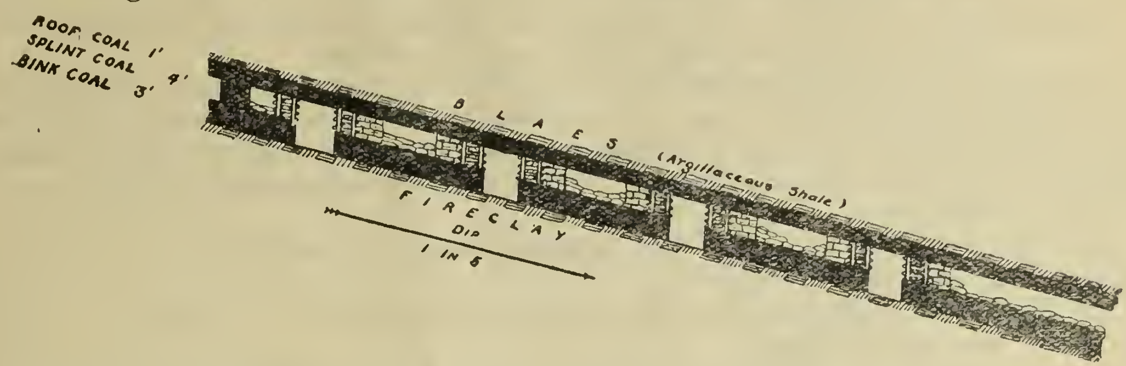

FIG. 52. CHEMISS SEAM. SECTION SHOWING METHOD OF WORKING THE SPLINT COAL.

From the description already given of the methods of working the Lochgelly Splint Seam it will be seen that the spontaneous heating of the goaf can be directly traced to the presence therein of heaps of coal. This coal has emanated from a variety of sources. The foul coal in the roof in the upper portion of the seam is normally left because it is economically unworkable. Formerly great quantities of slack were thrown back into the goaf by the workmen. Falls at the face are responsible for ribs and pillars of solid coal being left. All this coal either falls or is crushed in the waste, and fires invariably follow, the period elapsing between the formation of the waste and the outbreak of fire being variable and indeterminate. Cases were quoted by Mr. Rowan of fires occuring after a few months, and one fire broke out two years after the waste in its vicinity had been formed.

Mr. Rowan laid the greatest stress on the liability to heating from the inferior roof coal, but emphasised also the importance of removing all ribs and pillars. He did not attribute much importance to the removal of slack and small coal made in working, and assigned as proof of this the fact that fires have not diminished in number as a result of the policy of completely removing such slack. Be that as it may, in the Wemyss area no coal or slack is allowed to be thrown into the waste, and this practice is completely in accord with that followed in other coalfields of the United Kingdom.

In working the Dysart Main Seam, the top Splint Coal, containing 15 per cent. to 20 per cent. of ash, is left unworked, and fires are attributed to the crushing of this coal in the wastes. Pillars of coal left in owing to small faults or face falls are also considered as suspect.

The crushing of the roof coal during the first working of the Chemiss Seam was given by Mr. Kirkby as the cause of spontaneous combustion in that seam.

The witnesses from Fifeshire were fully alive to the dangers arising from the crushing of pillars of inadequate size and several instances were mentioned of fires in the solid having arisen from this cause. Not only are shaft pillars affected in this district, but barrier pillars, main road pillars, and solid rib-sides also, and Mr. Rowan remarked that "a great deal of heat is generated at all rib-sides by the "subsiding strata grinding on the solid coal." The problem of packing the wastes efficiently is a very serious one in Fifeshire, especially in working the Lochgelly Splint Seam, where there is frequently little or no dirt separating the two sections of coal. When working the lower seam it is often found that breaks occur and that air is consequently leaking upwards, heating the coal in the upper portion of the seam. For the same reason it is found extremely difficult to avoid leakage of air across gate road packs into the waste which are to a great extent very open.

(C) *Preventive Measures.*

(i) *The Methods in Operation for Preventing Gob-fires.*

As has been indicated, *Mr. Rowan* is strongly of opinion that the fires in the West Fife Coalfield are caused, to some extent at least, by the pressure on the coal of the superincumbent strata. Apart therefore from the special methods of working adopted, the main precautions advocated by him are:—

1. That all small coal should be removed from rib-sides and that space alongside such ribs should be permanently left to secure free passage of a ventilating

current. The fresh air which will then pass will be sufficient to carry off any heat generated, and the initiation of an outbreak due to spontaneous combustion will be prevented.

2. In ordinary working, either by longwall or pillar and stall, the leaving of small ribs and pillars of coal should be guarded against.

Mr. Rowan strongly advocated the use of hydraulic stowage in the mines of West Fife, declaring that by this system not only would the seams now being worked be extracted without loss, but also great quantities of abandoned coal would be rendered available. He was convinced that the system could be economically applied to the mines in his district.

Mr. Kirkby divided the fires due to spontaneous combustion that occur in the Wemyss area, into three classes, viz.: —

(i) Fires which occur in the centre of the waste in the fourth working, *i.e.*, away from the rib-sides.

He said that this class was caused by the crushing of the roof coal where it had been left.

(ii) Fires which occur in the course of working the first, second, or third leaves, in the centre of the wastes.

He said that "these have always been traced either to abnormal " crushing of the upper leaves of the coal by the working of the faces in " an irregular line, or to the crushing of a small pillar of coal left in, " owing to some local trouble or hitch, or to a small piece of coal which " has been left unworked between two advancing faces owing to the " recurrence of falls preventing the small pillars being got out."

(iii) Fires which occur against the rib-sides of panel barriers.

In this district every endeavour is made to secure adequate packing and stowage of the wastes. Where shortage of stowing material prevents this being effected to its fullest extent, the working districts are kept as cool as possible by good ventilation. This can only be done in the initial stages of spontaneous heating, and it had been Mr. Kirkby's experience that increased ventilation had the effect of increasing a fire once it had broken out. Attempts are made to prevent the roofs breaking down in the first, second and third workings, and success in this direction can only be attained when the workings are regularly and consistently advanced. The waste alongside rib-sides is carefully stowed. All coal, whether in the form of ribs or pillars, is removed from the waste as far as is possible. All slack and small coal is removed from the waste.

Mr. Kirkby also was strongly in favour of the application of the hydraulic system of stowage to mine wastes, especially in mines such as those of the Wemyss area, where there is always a serious shortage of hand-stowing material. This system was adopted on a small scale at Lochhead Colliery before the war and, according to Mr. Kirkby, it proved most successful both economically and technically. He stated that during the war period and up to date, over 135,000 tons of washery refuse had been introduced into the Lochhead pit workings and thereby over 160,000 tons of coal, previously sealed off and abandoned owing to fires, had been got. Mr. Kirkby gave up-to-date figures of working costs showing that the cost of stowage per ton of coal extracted through the application of hydraulic stowage worked out at 8*d*.

Mr. Kirkby expressed the opinion that probably the best method of working the Dysart Main Seam (assuming a section such as at Lochhead Colliery) would be to lay it out on the pillar and stall panel system, removing the pillars and packing the wastes by the hydraulic method. He said :—

"As we get to greater depths we experience more trouble with the crushing of the barrier pillars alongside the main roads. To be of any use these pillars require to be of large dimensions, and even large blocks of coal will probably not eliminate trouble from crushing at the barrier sides with fires resulting therefrom.

"To prevent fires, therefore, no pillars at all should be left at depths of from 250 fathoms downwards. In order to safeguard the main roads the only plan would appear to be to drive these in the metals below the coal seams, leaving a safe thickness of metals between the roof of this road and the longwall waste above.

" Crosscut mines can be driven out to the workable seams at suitable intervals, and the coal can be worked right out in areas of suitable size by concentrated methods in order to get as large outputs as possible from a few openings.

"Should a fire take place in one of these areas and it be found impossible to dig it out, the area can be dammed off in the crosscut mines, and the main roads in the stone will be quite safe."

(ii) *The Methods in Operation for Dealing with Gob-fires when they Occur.*

Mr. Rowan did not consider it advisable to lay down any definite ruling as to how a fire should be combated. Each case had to be dealt with according to the particular circumstances prevailing. In Fifeshire, however, the custom is to remove the burning material, wherever possible, by digging it out; and while Mr. Rowan considered that only quite small fires could be so treated, *Mr. Kirkby* stated that, given accessibility to the seat of fire and a plentiful supply of water, he was satisfied that any size of fire could be successfully loaded out. A complete system of underground water mains has been installed in various collieries belonging to the Wemyss Coal Company, and stocks of branch pipes are kept in readiness for extension to the site of an outbreak. The mains are connected to the rising main in the pumping shaft and a constant supply of water having a considerable pressure is thereby ensured.

Where water cannot readily be taken to a fire, success has been attained by the use of portable fire extinguishers, numbers of which are kept in readiness at the collieries. When fires in Fifeshire are so situated as to prevent the adoption of the methods just described, means are taken to exclude all air from the area affected. Where all movements due to subsidence has ceased, fires have sometimes been successfully dealt with in the West Fife area by building them off with a wall that has been thoroughly coated with clay. Usually, however, this method cannot be depended on and the district has to be rapidly and effectively sealed off. When the fire occurs in a panel, this can be done without great difficulty, but here, as in all other cases of sealing off, the success of the operation is entirely dependent on the complete prevention of air leakage. The principles are similar in each portion of the field though the dams used may differ in detail. Fig. 53 illustrates the type of stopping used in West Fife. Brick walls and arching, from six to ten feet long, are built into the opening, and a space left between the brickwork and the roof and sides. This space is rammed with sand, and according to Mr. Rowan, any crushing that takes place improves the seal, and also prevents the brickwork from being crushed.

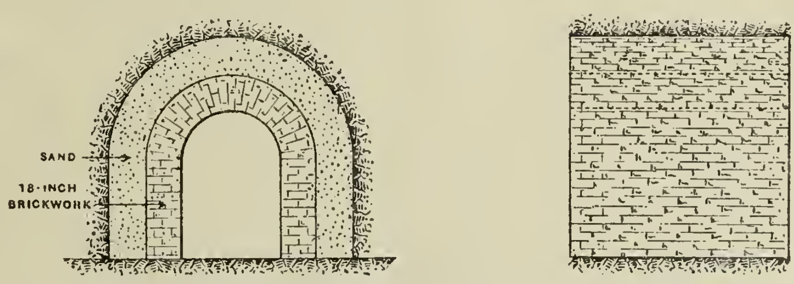

FIG. 53. BRICK STOPPING USED IN WEST FIFE.

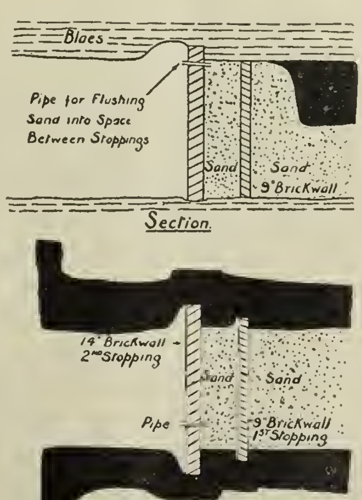

FIG. 54. TYPICAL FIRE STOPPING USED IN THE WEMYSS COALFIELD.

Fig. 54 is a typical fire-stopping used in combating the fires occurring in the Wemyss coalfield. In several cases where a single dam had been constructed failure resulted through leakage of air taking place round the edges of the brickwork. In such cases a second dam is built as illustrated.

The first operation is to stow the opening as solidly as possible with dirt or sand. A 9-inch brickwork wall let well into the sides is then built. A site is then prepared some feet back from the face of this wall and the intervening space filled with sand. A second wall 14 inches thick is then erected and into this is built a pipe. When the wall is complete, water and sand are flushed through the pipe until the space between the two walls is completely filled.

SECTION IV.

HYDRAULIC STOWAGE.

With a view to determining how far it would be practicable to adopt in the mines of the United Kingdom the method of packing the wastes known as hydraulic stowage, which is largely practised on the Continent, we commissioned *Mr. K. Seidl* (*see* page 31) to visit and inspect collieries in North and South Staffordshire, Warwickshire, South Yorkshire, South Wales and Monmouthshire. His report is published *in extenso*, together with plans and sections illustrative of his findings, in Volume 2 of the Minutes of Evidence.

The report in question is divided into the following sections:—Part I. dealing with—

(1) Objects of the method in Germany and other countries abroad.
(2) Technical considerations.
(3) Results obtained.
(4) Cost.

Section (2) is subdivided into:—Material; surface plant; pipe lines; methods of working and cost of timber; and clarification of the stowage water.

Section (3) is subdivided into:—Prevention and combating of underground fires; effect of hydraulic stowage on the surface.

Part II. of the Report deals with hydraulic stowing in Great Britain, and this part is subdivided into:—

(1) Consideration of hydraulic stowing methods under conditions prevailing in England as compared with the Continent.
(2) Stowing material.

Part III. is devoted to South Staffordshire and Warwickshire.
Part IV. is devoted to North Staffordshire; and
Part V. to South Yorkshire. These last three are also subdivided into:—

(1) Natural conditions.
(2) Methods of working.
(3) Spontaneous combustion.
(4) Hydraulic stowage.

It is an undoubted fact that, under certain conditions, the application of hydraulic stowage to wastes is an economically sound proposition, and one that has led in many cases on the Continent and elsewhere to a reduction in the liability to spontaneous combustion of coal or other carbonaceous material in the mines. By far the greater number of fires in the mines of this country occur in the wastes of worked-out coal seams, due, in a great measure, to the fact that perfect consolidation is not attained until after the lapse of a considerable period. This delay in consolidation allows a continual leakage of air, setting up conditions which are favourable to spontaneous combustion. It stands to reason, therefore, that if the "containing chamber" can be *completely* filled with some foreign material more or less approximating in density and bulk to the excavated material the conditions suitable to heating and ultimate ignition will automatically be eliminated.

Unfortunately, it is not possible either from an economical or from a technical standpoint to apply hydraulic stowage to every mine. Certain features must be taken into consideration, and these are summed up by Mr. Seidl as follows:—

"With the introduction of hydraulic stowage in a colliery, the ordinary working conditions (weight and behaviour of the roof, loss of coal, timbering, working costs, &c.) alter appreciably. The heavy costs of hydraulic stowage could certainly not be borne by many mines which have had to introduce it in order to prevent spontaneous combustion if this system did not bring with it a number of other economic advantages. It is, therefore, impossible to express an opinion as to whether it would be financially feasible to adopt hydraulic stowage in British mines as a safeguard against spontaneous combustion, unless one is familiar with all the details of the method, with its effect on the general working of a mine, and unless one knows what the underground working costs are under the present system of hand stowing."

The various methods of working already successfully treated on the Continent are :—

(1) Pillar working in thick seams—with gradients up to 30°.
(2) Pillar working in thin seams—either flat or highly inclined.
(3) Panel working (*Stossbau*) in thick seams.
(4) Panel working in seams of medium thickness (less than 10 feet).
(5) "*Strebbau*," a method somewhat resembling the English "Longwall" system.

The results observed abroad from the hydraulic stowage of the wastes in the methods of working above mentioned were described by Mr. Seidl as follows :—

(1) "*Protection of the workings against adjoining fires.*—Formerly barriers 150 feet wide or more were left all round the seat of the fire, often whole districts, even whole seams, had to be dammed off owing to danger due to fires. Nowadays the whole goaf surrounding the fire is encircled by a belt about 60 feet wide of hydraulically stowed waste ; this ensures absolute protection to the adjoining workings and in addition loss of coal is mostly or absolutely avoided.

(2) "'*Foudroyage*' (*i.e.*, working the seam out without building any waste packs whatsoever) or *hand-packing superseded by hydraulic stowage in seams liable to spontaneous combustion.* This has entirely done away with the danger of underground fires. Formerly certain mines working thick seams, as for instance in Upper Silesia (*e.g.*, "Myslowytz," with 66 feet coal), could hardly go on working at all ; at the present day underground fires are practically unknown.

(3) "*Protection against possible fires.*—In Upper Silesia, at times, strips of hydraulically stowed waste are formed according to a plan in the solid coal ; the districts or panels thus mapped out are completely isolated from each other, and, at a later date, worked out by *foudroyage*, *i.e.*, without any system of packing the goaves. When experience has taught that three months, for instance, after working the coal, fires are liable to start in the gobs, the size of the panel isolated by the belt of hydraulic stowage is so arranged that it can be completely worked out within that time. Should a fire start later on in the panel goaf, this will have already been localised and isolated.

(4) "*Extinguishing open fires.*—When fires have occurred in ribs or airways, these have often been efficiently stowed hydraulically, and by this means the fire has been put out. On many occasions also, fires in the wastes have been extinguished without delay simply by flushing them. However, two instances are known where the flushing of the wastes on such occasions caused explosions In neither case was fire-damp present."

No opinion as to the cause of those two explosions was offered by Mr. Seidl, and he said that while the flushing of waste had frequently been adopted for the purpose of drowning gobs which were on fire, these were the only two authentic instances where explosions have resulted.

Mr. Seidl discussed the effect of hydraulic stowage on the surface, and stated that the amount of subsidence was regulated by, among other things, the compressibility of the wastes. Following on that he said :—"the compressibility of the wastes
" depends on the material. Fine-grained material tends to fill a hollow space more
" efficiently than large sized material ; the latter, however, is more compact in itself
" than the former ; the best mixture, therefore, is large sized material embedded in
" fine-grained material.

"Pure sand is the least compressible, blast furnace slag and stone debris, if "broken to small pieces, are slightly compressible; far more compressible are loamy "sand, shales, and particularly washing-refuse and boiler ashes; the worst of all is "granulated slag."

Part II. of Mr. Seidl's report is of interest because of the very definite pronouncement he makes therein regarding the effect of hydraulic stowage on spontaneous combustion. He said :—"Generally speaking, the hydraulic stowing system is "obviously the most efficient safeguard against underground fires, both under "conditions prevailing in the British Isles and on the Continent. Hydraulic stowing "renders it possible to work seams without any loss of coal whatever, and prevents "any circulation of air through the wastes. Any mine, therefore, adopting hydraulic "stowage at any rate must be absolutely safe-guarded against gob-fires."

In Part II. also, Mr. Seidl deals with the question of stowage material and the availability of supplies in each of the districts he reviewed. On this important feature he expressed grave doubts (at least in the majority of the colliery areas) as to there being a sufficiency of suitable material at hand; he said :—

"Should no adequate and workable deposits of sand be discovered in, or in "close vicinity to, the districts requiring it, the problem of providing the necessary "stowing material will be, in the great majority of cases, one of extreme difficulty. "As far as I am able to judge at present, North Staffordshire is the district richest in "hydraulic stowing material (large refuse heaps at the collieries and from the "potteries). In South Staffordshire, the companies resorting to hydraulic stowing "could use their own debris and then buy the refuse heaps and debris outputs "from their neighbours. The large collieries of Yorkshire must get their material "from a distance at the very outset."

With regard to South Staffordshire and Warwickshire, after discussing the natural conditions of those areas, the precautions taken against spontaneous combustion, and the methods of working, Mr. Seidl said :—

"There would be no technical difficulties in carrying out hydraulic stowage in "these districts. The conditions would be the same as in many instances in Upper "Silesia where operations are carried out on an extensive scale, but it is impossible "to suggest one method of working suitable to all mines in the districts. The "coal could as a rule be worked on the same principle as the pillar system "(Figs. 3 and 4)*; modifications would, however, have to be brought in in each "particular case."

As to North Staffordshire Mr. Seidl said :—

"There would be no technical difficulty in applying the hydraulic system to "North Staffordshire. The thickness of the seams, the inclination and method of "working, are exactly the same as on the Continent in most cases where the wastes "are flushed."

With regard to its economical possibilities in this district, he considered that a close comparison must be made between the present costs of combating the fires and the cost of installation of a stowage system, and after discussing these points he concluded by remarking that: "there are probably cases in North Staffordshire, if not "of whole mines, at least of seams or parts of seams where . . . . . hydraulic "stowing could be adopted with financial success."

He was not so confident that the system could be successfully applied to the longwall workings of South Yorkshire. After detailing the principles on which rest the particular advantages of the longwall system practised in this district, he said :—

"It follows, therefore, that the adoption of hydraulic stowing in the South "Yorkshire mines as a means of prevention of spontaneous combustion could only "be considered as a practical solution of the problem if this system could be applied "in a suitable manner to the conditions of the longwall method."

He enumerated some of the probable difficulties, viz. :—

(*a*) Adverse effect of water on roof and floor.

(*b*) Adverse effect of increased humidity on health and working capacity of the workmen.

(*c*) Installation of portable pumps for drainage of water from a series of sumps along the face. ("Such a scheme would be impracticable and the cost "prohibitive, and it could only be adopted in very exceptional cases.")

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* Vol. II., Minutes of Evidence

As to the "economy of the hydraulic system," he summed up his remarks as follows :—Yorkshire with its large requirements of material, could only get sand from "outside the district." This would materially add to the already high cost estimated by him for Yorkshire. "Under these conditions it would be prohibitive to introduce "hydraulic stowage simply as a safeguard against spontaneous combustion."

He suggested an alternative method of combining hydraulic stowage with longwall, but at the outset declared that it would be most impracticable, being contrary to the very principle of the longwall system, and he concluded his report by saying :—

"Unless other considerations prevail (such as the working of shaft pillars, the "simultaneous exploitation of several overlying seams, &c.), the problem of preventing "spontaneous combustion in longwall workings cannot be solved by the adoption of "hydraulic stowage."

We agree in the main with the majority of Mr. Seidl's conclusions, but owing to the extreme variation of conditions existing in each of the districts reviewed, and indeed in nearly every individual colliery, we find ourselves unable to lay down any definite recommendation in regard to the adoption of hydraulic stowage as a means of preventing spontaneous combustion underground.

We do, however, confidently urge upon Coal and Royalty Owners the necessity for the most careful and earnest consideration of the principles underlying the hydraulic stowage of wastes. The system has already been successfully applied to collieries in Fifeshire, and we are convinced that there are other cases where its adoption is practicable.

SECTION V.

CONCLUSIONS AND RECOMMENDATIONS.

The conclusions which we have arrived at as to the scientific explanation of the self-heating of coal in mines have been stated on pages 29 and 30 of this Report and need not be recapitulated.

With regard to Section III., which deals entirely with the practical aspect of the subject, we have, after careful consideration of the evidence, reached certain main conclusions, which we now briefly summarise.

I.—Liability of Coal to Spontaneous Combustion.

Probably all bituminous coal is liable to spontaneous combustion in some degree, but the fact that there is greater liability to self-heating of the coal in the seams of some coalfields of the United Kingdom than in others is due to several causes other than the chemical composition of the coal, thus :—

(a) *Thickness of Seams.*—Speaking generally the thicker the seam the greater the liability to spontaneous combustion. With rare exceptions, the heating process, in seams of coal less than four feet in thickness, is not carried to such an extent as to induce combustion.

(b) *Crushing of Pillars.*—Coal which has become crushed in the mine by reason of superincumbent weight is more likely to induce self-heating than coal in a solid compact state. For this reason it is in the highest degree desirable that (in seams liable to spontaneous combustion) pillars should be adequately designed to resist all pressures, and that during the process of their removal (which should not be long delayed), work should be as consistent and rapid as possible (*see* page 29). For the same reason inferior coal, normally left, *e.g.*, in the vicinity of faults, should be extracted and sent out of the pit.

II.—Faults.

Faults indirectly contribute to the self-heating of seams of coal, which without these extraneous agencies might not take fire. This is due not only to the presence of inferior and soft coal adjacent to the faults, but also to the interference of the latter with the regularity of the line of face, and to their constituting lines of weakness contributing to falls of roof and admission of air.

III.—Condition of Roof.

The character of the roof of a coal seam plays an important part in the liability of the coal to spontaneous combustion. A broken or unstable roof permits the percolation of air, and the leaving of top coal for its maintenance introduces a factor conducive to fire in the goaf when such coal breaks down too far back for complete recovery.

IV.—Other Conditions.

The following conditions are also conducive to spontaneous combustion:—

(a) *The uneven and incomplete Settlement of the Goaf, Gob, or Waste.*—Where this occurs the goaf has large spaces to which sufficient air may have access to promote the oxidation of any carbonaceous material present, but in which there is no constant through current to provide a counteracting cooling effect.

(b) *The leaving of Timber in the Goaf.*—Timber left standing in the waste workings of a mine is not a primary cause of spontaneous combustion. It is so indirectly, inasmuch as it hinders the even settlement of the roof, and allows of the formation of cavities or air-spaces. It may be, also, that in the presence of timber, which is more easily ignited than coal, fire breaks out at an earlier stage of heating than it otherwise would. In mines liable to spontaneous combustion, therefore, the extraction of timber should be carried out as far as is compatible with safety.

(c) *The presence of Coal and Timber in the Packs.*—We are aware that there are cases where coal has been largely used in the construction of packs without the liability to spontaneous combustion being incurred therein, but this has been because of the peculiar character of the coal so employed. In fact, witnesses almost unanimously condemned the practice, and, undoubtedly, it has in the past been a frequent cause of fire. No timber should be either built in or used as a roof support in the construction of packs, except in the case of cogs or chocks placed on the road-side of packs when these cannot be dispensed with, *e.g.*, in highly inclined roadways.

V.—Systems of Working.

With regard to this aspect of the case, it is impossible to lay down any hard and fast rule for universal application, and the method adopted must be conditional on the circumstances. Broadly speaking, we are satisfied that the methods of working in operation in the several districts with which we have dealt, are those which are the most practical, and which, in the circumstances, are best calculated to get the coal with the least risk of danger from fire, affording at the same time the greatest facilities for dealing with outbreaks. In some cases, however, the manner in which these systems are carried out in detail is not, in our opinion, as perfect as it might be, and we have pointed out some of the deficiencies in the body of this Report.

In all mines liable to spontaneous combustion the following precautions in respect of methods of working are desirable:—

(a) *Longwall Method.*—Wherever the natural conditions (*e.g.*, thickness and inclination of the seam, and character of the roof) allow of its application, the longwall system of working should be practised. The face should be kept as straight as possible, and advanced consistently and rapidly.

(b) *Retreating Method of Longwall.*—In those seams which give off fire-damp freely, and which by reason of their thickness are suitable for its application, the retreating method of longwall should be adopted.

(c) *Packs.*—Packs should be made as wide as practicable in relation to the distance between "gates." The thicker the seam the wider should be the packs, which should be solidly built and well-faced.

(d) *Gate Roads.*—The distance between the gates should be such as, whilst permitting of the quick, regular, and complete settlement of the goaf, to reduce the number of gate roads to the minimum, so decreasing the possibility of leakage of air. Where practicable the packs should be buried as soon as possible.

(e) *Panel Systems.*—Where experience has shown that the system of working—whether modified longwall or pillar and stall—should be by panels, the immediate entrance to each panel should be limited to two roads provided with arrangements for rapid and effective sealing-off in case of an outbreak of fire.

(f) *General Precautions.*—All roads no longer required for haulage, travelling, or ventilation should be closed with good air-tight packs, so that there will be less liability of spontaneous combustion taking place therein. Such roads as may be required to be kept open should be travelled and examined daily.

As a high pressure of ventilating current conduces to leakage, it should not exceed what is necessary to ventilate the mine properly, and the space between the face and the gob should be sufficiently large to prevent the forcing of air through pack walls. Generally, the airways should be of large area, and there should be a large number of splits. The ideal in ventilation is a large quantity of air at a low water gauge; leakage of air into undesirable places will thus be reduced to a minimum.

No coal posts or pillars should be left, if possible. No slack or coal should be left in the goaf.

Where heatings or fires are of frequent occurrence, an adequate supply of water (under pressure) should be provided for immediate use where advisable.

VI.—Organisation.

At large collieries liable to spontaneous combustion there should be provided a specially trained official or officials whose duty it should be to investigate any occurrence of gob-stink or other indication of self-heating, and to deal with any outbreak of fire. These officials should be under the direct control of the certificated manager of the colliery and report to him daily.

We recommend to the serious consideration of colliery owners and managers the organisation set up by Mr. J. T. Greensmith, at Brodsworth Main Colliery (*see* pages 77 and 81). Perhaps more is to be hoped for from organisations such as this and from precautions adopted as the result of practical experience than from any other source. It is a fact that since the commencement of our inquiry in 1912, when considerable apprehension existed in the minds of many as to the future of the South Yorkshire coalfield owing to the prevalence of gob fires, a very marked improvement has taken place, and fires are now, comparatively speaking, of rare occurrence.

VII.—Hydraulic Stowage.

We commend to the careful consideration of mining engineers the report by Mr. Seidl on Hydraulic Stowage, and the evidence of other witnesses, especially that of Mr. R. Kirkby. There is no doubt that the application of the process would result in a diminution—probably in the complete prevention—of gob-fires, but the application of the process necessitates ample quantities of easily accessible and suitable stowage material. The process has been successfully applied in the Fifeshire coalfield.

VIII.—Cementation.

We recommend that mining engineers should consider the application of the cementation process to combating fires that have occurred in main roads, ribs, and pillars.

IX.—Further Regulations unnecessary.

We do not recommend the establishment of regulations additional to those brought into force in July last, which were based upon our Interim Report, and which we regard as sufficient under present circumstances.

In concluding this Report we wish to record our appreciation of the great help which has been voluntarily rendered to us by the witnesses—scientists, mining engineers, and workmen. We would also acknowledge our indebtedness to the secretaries of the Committee, viz., Mr. Granville Poole, who was secretary in the early stages of our proceedings; Mr. G. B. Brown, who was acting secretary during the greater part of our inquiry; and to Mr. J. A. Kilpatrick in particular, who towards the close of our inquiry has been of much assistance to us.

We have the honour to be,
Sir,
Your obedient servants,

R. A. S. REDMAYNE (*Chairman*).
FRANK RIGBY.
J. H. W. LAVERICK.

APPENDICES.

APPENDIX A.

Note by Dr. R. V. Wheeler on a Comparison of the Rates of Oxidation of Pyritic and Non-Pyritic Coals.

Samples of coal from two sources were obtained: from the Barnsley Seam, Brodsworth Main Colliery, and from the Bullhurst Seam, Minnie Pit.

Several blocks of each were taken from freshly exposed faces, the samples being chosen to contain (*a*) as much, and (*b*) as little pyrites as possible. For the experiments herein described the blocks of pyritic coal only were used. These were carefully divided and yielded samples containing high proportions of pyrites as well as samples of nearly pure coal. The samples were ground to pass through a 10 × 10 mesh sieve.

Description of Bulk Samples.—Barnsley Seam, Pyritic Coal.—A banded coal, of moderately bright general lustre. Many bands (often lenticular) of vitrain were present. These were of various widths, ranging from hair-like streaks to bands of 2–3 mm., with several bands of 6–10 mm. thickness. Many streaks of pyrites, greyish yellow to brass in colour, were present, of varying thicknesses, from very fine up to 8 mm. There was a large band of fusain, 5 mm. thick, across the block. All streaking was parallel to the bedding plane. Most of the pyritic streaks were in the middle of the block, the outer portions being apparently almost pure coal. A vertical section of the coal was cut, and the middle portion of this, comprising two large and many small pyritic bands, was taken (sample A). The outside layers of pure coal were also separated (sample B).

Bullhurst West "Billies."—A faintly banded, bright coal, containing frequent streaks of vitrain, and occasional layers of fusain. There were many layers of pyrites, both grey and yellow in colour, varying from very fine to 4 or 5 mm. in thickness. The coal fractured very readily, at right angles to the bedding plane, with a fracture mostly fibrous, but in places conchoidal. The vertical cracks were often filled with mineral matter, which in some instances was "amorphous" pyrites. The block was sawn into pieces and two sections containing much pyrites were taken (sample C). A layer of nearly pure coal was also taken (sample D).

Method of Experiment.—Experiments were made in the apparatus used for the relative rates of oxidation of the ingredients of banded coal (vitrain, clarain, durain, fusain). This apparatus provides means for the circulation, during a prolonged period, of a charge of oxygen or air through the finely-divided coal maintained in a reaction-tube at any desired experimental temperature; and the coal can, if desired, be isolated from the rest of the apparatus for purpose of exhaustion. During circulation of the oxygen its rate of absorption is determined by observations of the fall of pressure within the apparatus.

Twenty grams of the coal under examination were placed in the reaction-tube and exhausted at 200° C. during 2 hours to remove occluded gases. Pure oxygen was then introduced and circulated through the coal, maintained at 30° C., during 96 hours. The coal was then re-exhausted at 200° C. *in situ* and a second circulation of pure oxygen through the coal then made, during 96 hours, the temperature being maintained at 100° C.

The four coal samples described above were treated in an exactly comparable manner. The results are shown in the table that follows, and diagrammatically in Figs. 55 and 56.

Table.

Absorption of Oxygen: Ccs. during 96 hours, per gram of Coal.

—	At 30° C.		At 100° C.	
	Pure.	Pyritic.	Pure.	Pyritic.
Barnsley Seam	3·94	3·61	59·9	42·7
Bullhurst "Billies"	2·00	1·28	27·2	24·0

The results show clearly that, under the conditions of experiment, the presence of pyrites does not increase the rapidity of oxidation, but exerts a hindering action, probably acting in the same manner as any other inert material.

The proportions of pyrites (FeS_2) contained in the samples, as ascertained by analysis, were: Sample A, 17 per cent.; sample B, 7 per cent.; sample C, 36 per cent.; sample D, 5 per cent.

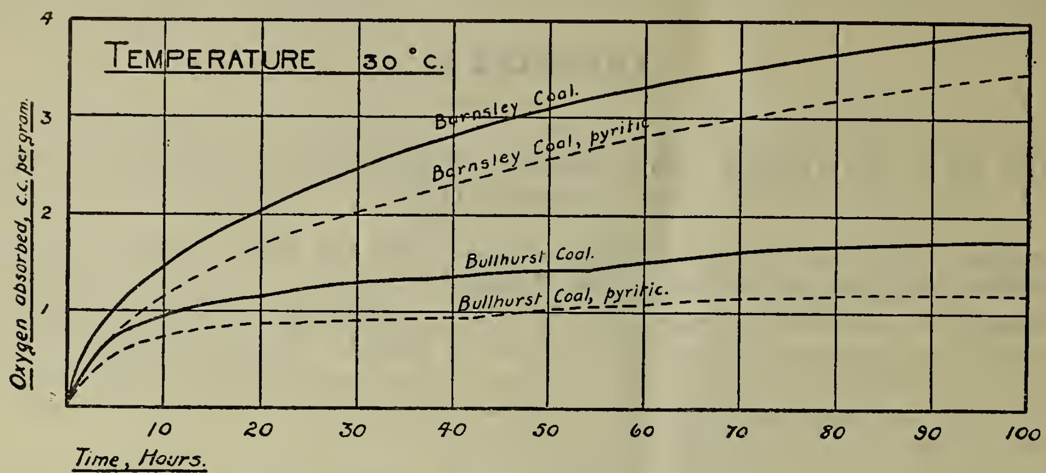

FIG. 55.

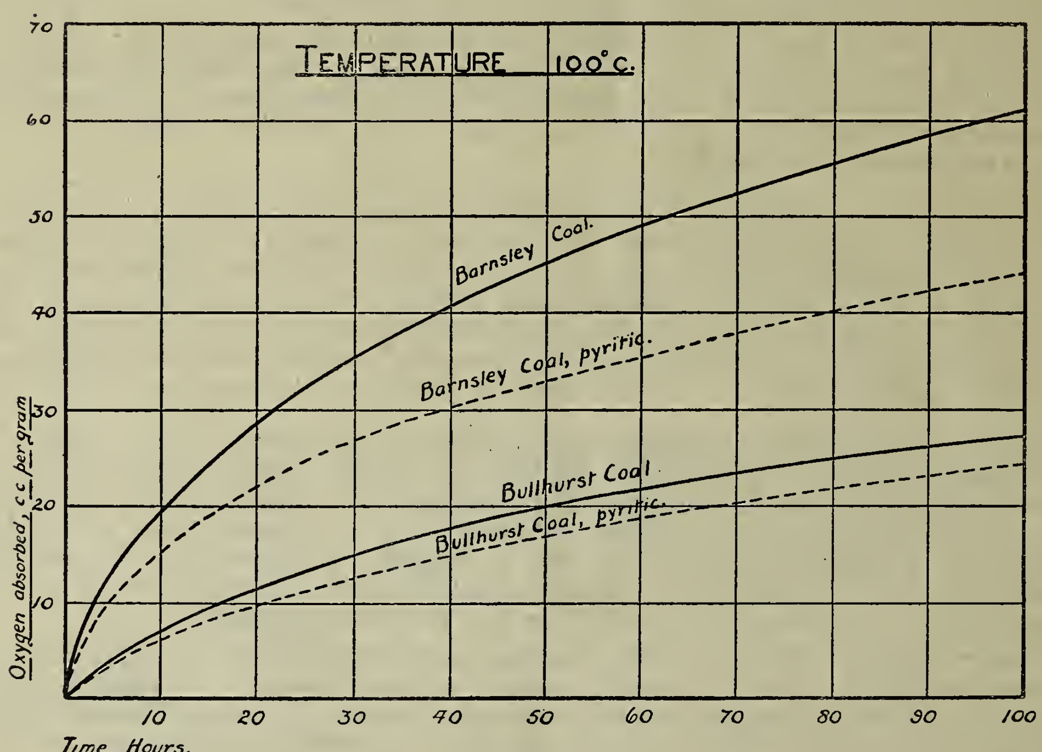

FIG. 56.

APPENDIX B.

NOTE BY DR. R. V. WHEELER ON THE IGNITION AND OXIDATION OF COAL.

The experiments on the relative ignition-temperatures of different coals were carried out in the following manner.

Forty grams of the powdered coal that had passed through a 150 by 150 and remained on a 240 by 240 mesh sieve were placed in a glass tube of the form shown diagrammatically in Fig. 57 making a column about 12 cm. long. This tube was fixed vertically in an electrically

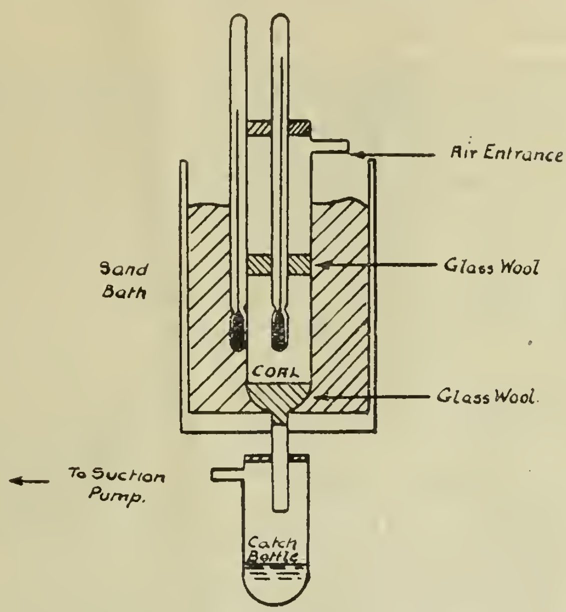

FIG. 57.

heated sand-bath, and a current of air (dried by passing through calcium chloride towers) drawn through it at a constant speed. The temperature of the sand-bath was then slowly raised, at a uniform rate, and simultaneous readings of two thermometers, the one embedded in the coal and the other in the sand, taken at frequent intervals of time.

In this manner, two time-temperature curves were obtained, the one showing the rate of rise of temperature of the sand-bath and the other the rate of rise of temperature of the coal. At a given temperature, depending on the coal employed, these two curves cut one another. This temperature was taken to be the ignition-temperature of the coal relative to other coals tested in the same manner.

In Fig. 58 an example of the results obtained is given. Only the later portions of the two curves are shown; during the earlier stages of the heating (from atmospheric temperature)

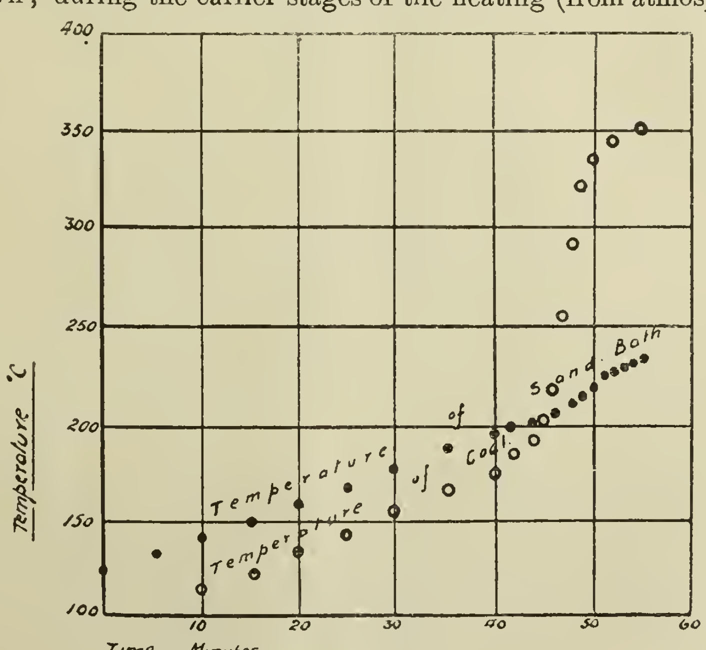

FIG. 58.

the curves run parallel to each other. It will be seen that the temperature at which the reaction-velocity became so rapid that the inflammation of the coal was imminent is clearly indicated at about 205°. It is evident also from the gradual approach of the two curves that the heat due to oxidation of the coal was sufficient, despite loss to the outgoing air, to raise the temperature of the coal above that normally due to the heat received from the sand-bath when the reaction was proceeding at a temperature of 125°. The latter temperature might be regarded as the ignition temperature of the coal (that is, the temperature at which self-heating began) under the conditions of the experiment. For comparative purposes, however, it was found preferable to record, as the relative ignition-temperature, the point at which the coal-temperature curve and the sand-bath curve cut one another, for this point is clearly defined. It is the temperature at which rapid self-heating begins, and is therefore in conformity with Nernst's definition of the ignition-temperature for gaseous mixtures.

To determine the rates of absorption of oxygen by different coals an apparatus was employed, constructed wholly of glass, which enabled a continuous stream of air or oxygen to be circulated through the sample of coal to be tested. The coal was contained in a horizontal reaction-tube, 1·5 cm. in diameter, maintained at the experimental temperature by means of an electrically heated air-oven. (*See* Fig. 59.) Suitable stop-cocks in the circuit enabled the reaction-tube to be by-passed, or to be exhausted separately from the rest of the apparatus. A by-passed calcium chloride tube, for drying the gases, was included in the circuit.

Twenty grams of the coal, undried and broken into pieces capable of passing through a 10 × 10 and remaining on a 60 × 60 mesh sieve, were packed tightly in a reaction tube and held in position by plugs of glass wool. The coal was then exhausted during 48 hours at the ordinary temperature, and finally at 200°, the gases removed (the original occluded gases) being collected and analysed. In the meantime, the remainder of the apparatus (the volume of which could be adjusted to be 1,100, 2,100, or 3,100 c.c. as required) had been filled with oxygen at rather more than atmospheric pressure, and circulation begun, through the by-pass of the reaction tube, by means of an automatic mercury pump.

The coal having been brought to the experimental temperature, the reaction-tube was included in the circuit which formed a closed system, and readings of the gas pressure were at once taken. Thereafter, readings of the temperature, gas pressure and barometer were taken at frequent intervals during 120 hours, the rate of circulation of the oxygen through the coal being maintained at 1 litre per hour.

At the end of the circulation period of each experiment (which yielded time-pressure curves, from which the rate of absorption of oxygen by the coal could be calculated) the coal was rapidly cooled to the ordinary temperature, and the gases remaining in the reaction tube were removed by exhaustion during several hours and transferred to the main part of the apparatus. The temperature of the coal was then raised to 200°, and the gases obtained by exhaustion during 24 hours collected separately and analysed. A sample of the oxygen (containing carbon dioxide and carbon monoxide) in the main part of the apparatus was also taken.

After allowing the reaction-tube to cool to the temperature required for the next experiment, fresh oxygen was introduced into the apparatus, and the cycle of operations repeated.

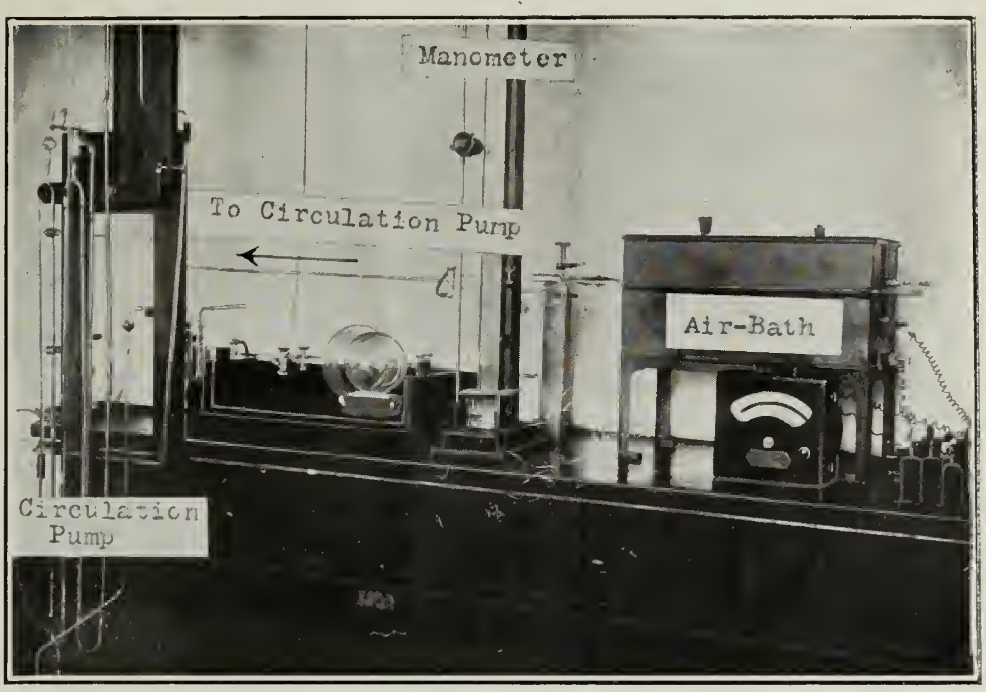

Fig. 59.

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